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PRACTICAL MECHANICS HANDBOOK

BY

F. J. CAMM

Editor of

"Practical Engineering" and "Practical Mechanics"

With 390 Illustrations

Fifth Edition

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PREFACE

WITHIN the course of my many years association with the engineering, aeronautical, automobile, wireless, and allied industries, in my capacity as engineer and designer, I found that most of the works of reference contained a great deal of matter which I did not require, and a small proportion of material to which I made constant reference. Tabular matter particularly is useful, for it saves continuous and involved calculations, and relieves the memory of the need for storing difficult formulæ and data. Most of the workshop handbooks suffer from the defect that they include material of interest only to very few and omit information which the majority seek.

Therefore, in this volume I have endeavoured to include matter and tables which I know from experience are most required and which my experience as Editor of a number of journals indicates are wanted. I handle some thousands of queries relating to a great diversity of subjects in the course of a year, and for a long time I have felt that a handbook such as this was needed.

I have endeavoured to bring this information together between the covers of this 400-page book, and I have included a fully cross-referenced index to enable readers rapidly to trace the information they seek.

It is hoped that the tabular matter in this book will be appreciated, and that the selection of tables covers the needs of those engaged in the mechanical trades. Thus, I have covered the lathe, small tools, filing, fitting and marking out, the dividing head, the micrometer and vernier, mensuration, screw cutting, gear cutting, hardening and tempering, case hardening, the chemical colouring of metals, electro-plating, silver soldering, brazing, welding, soft soldering, soldering aluminium, obtaining a patent, the metric system, pattern making, battery charging, sharpening woodworkers' tools, polishing and finishing metal, mechanical drawing, blueprints, weights and measures, glues, cements and adhesives, and so on.

It is believed that mechanics, engineers, and draughtsmen will find this volume more convenient in its arrangement, contents, and indexing, than many others appealing to the same interests.

F. J. CAMM.

CONTENTS

PRACTICAL MECHANICS HANDBOOK

MENSURATION

A and a = area; b = base; C and c = circumference; D and d = diameter; H and h = height; n° = number of degrees; P and p = perpendicular; R and r = radius; s = span or chord; v = versed sine

Square.—$a = \text{side}^2$; side $= \sqrt{a}$; diagonal = side × $\sqrt{}$ Rectangle or parallelogram, $a = bp$. Trapezoid (two sides parallel), a = mean length parallel sides × distance between them. Triangle, $a = \frac{1}{2}bp$. Irregular figure, a = weight of template ÷ weight of square inch of similar material.

Side of square multiplied by 1·4142 equals diameter of its circumscribing circle. A side multiplied by 4·443 equals circumference of its circumscribing circle. A side multiplied by 1·128 equals diameter of a circle of equal area. Area of inscribed circle multiplied by 1·273 equals area of the circumscribing square.

Circle.—$a = \pi r^2 = d^2\frac{\pi}{4} = 0{\cdot}7854d^2 = 0{\cdot}5cr$; $c = 2\pi r = d\pi = 3{\cdot}1416d = 3{\cdot}54\sqrt{a}$ = (approximately) $\frac{22}{7}d$. Side of equal square $= 0{\cdot}8862d$; side of inscribed square $= 0{\cdot}7071d$; $d = {\cdot}3183c$. A circle has the maximum area for a given perimeter.

Annulus of circle $a = (D + d)(D - d)\frac{\pi}{4} = (D^2 - d^2)\frac{\pi}{4}$.

Segment of Circle.—a = area of sector − area of triangle

Length of arc $= \pi\frac{n^\circ r}{180} = 0{\cdot}0174533n^\circ r$; length of arc

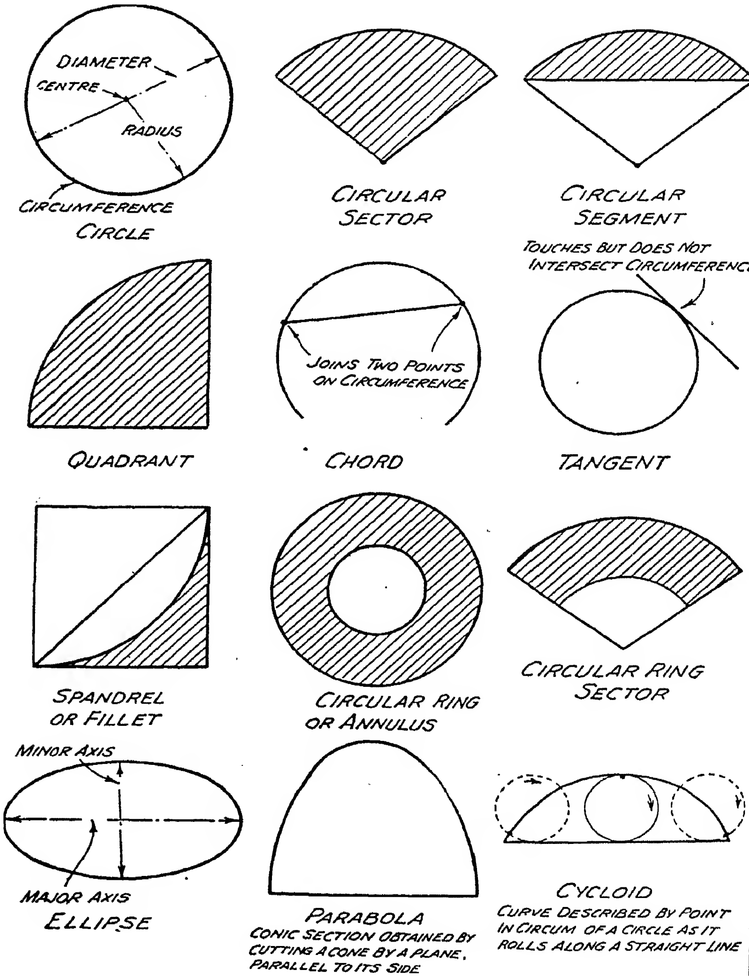
$$\sqrt{\frac{s^2}{4} + v^2} - s\Big)$$

approx. length of arc $= \frac{1}{3}$ (8 times chord of $\frac{1}{2}$ arc − chord of whole arc).

$$d = \frac{(\frac{1}{2}\text{ chord})}{v} + v;\ \text{radius of curve} = \frac{s^2}{8v} + \frac{v}{2}.$$

Sector of circle, $a = 0{\cdot}5r$ × length arc; $= n^\circ$ × area circle ÷ 360. **Ellipse,** $a = \frac{\pi}{4}Dd = \pi Rr$; c (approx.) $= \sqrt{\frac{D^2 + d^2}{2}} \times \pi$; c (approx.) $= \pi\frac{Da}{2}$.

Parabola, $a = \frac{2}{3}bh$. **Cone or pyramid,** surface $= \frac{\text{circ. of base} \times \text{slant length}}{2}$ + base; contents = area of base × $\frac{1}{3}$



Figs. 1 *to* 12.—*Plane Figures.*

vert. height. **Frustum of cone,** surface $= (C + c) \times \frac{1}{2}$ slant height + ends ; contents $= 0{\cdot}2618h(D^2 + d^2 + D\ d)$;

$\frac{1}{3}h(A + a + \sqrt{A \times a})$.

Wedge, contents $= \frac{1}{6}$(length of edge + 2 length of back)bh. **Prism,** contents = area base × height.

Sphere, surface $= d^2\pi = 4\pi r^2$; contents $= d^3 \frac{\pi}{6} = \frac{4}{3}\pi r^3$.

Segment of sphere, r = rad. of base ; contents $= \frac{\pi}{6} h(3\ r^2 + h^2)$; r = rad. of sphere ; contents $= \frac{\pi}{3} h^2(3r - h)$. **Spherical zone,** contents $= \frac{\pi}{2} h(\frac{1}{3}h^2 + R^2 + r^2)$; surface of convex part of segment or zone of sphere $= \pi d$ (of sph.) $h = 2\pi rh$. **Mid. sph. zone,** contents $= (r + \frac{2}{3}h^2) \frac{\pi}{4}$. **Spheroid,** contents = revolving axis^2 × fixed axis $\times \frac{\pi}{6}$.

Cube or rectangular solid, contents = length × breadth × thickness. **Prismoidal formula** contents =
$\frac{\text{end areas} + 4 \text{ times mid. area}}{6} \times$ length. **Solid of revolution,** contents = a of generating plane × c described by centroid of this plane during revolution. Areas of similar plane figures are as the squares of like sides. Contents of similar solids are as the cubes of like sides.

Rules relative to the Circle, Square, Cylinder, etc.—

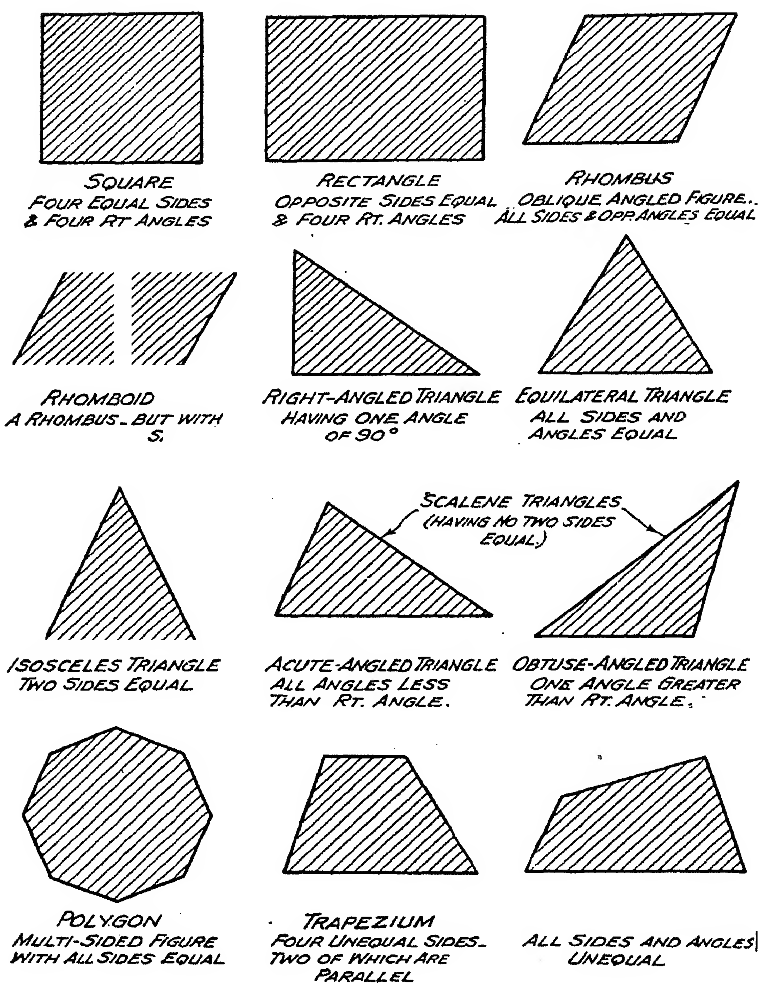
To find Circumference of a Circle :
- Multiply diameter by 3·1416 ; or
- Divide diameter by 0·3183.

To find Diameter of a Circle :
- Multiply circumference by 0·3183 ; or
- Divide circumference by 3·1416.

To find Radius of a Circle :
- Multiply circumference by 0·15915 ; or
- Divide circumference by 6·28318.

To find Side of an Inscribed Square :
- Multiply diameter by 0·7071 ; or
- Multiply circumference by 0·2251 ; or
- Divide circumference by 4·4428.

To find Side of an Equal Square :
- Multiply diameter by 0·8862 ; or
- Divide diameter by 1·1284 ; or



Figs. 13 *to* 24.—*Further Plane Figures.*

Multiply circumference by 0·2821; or
Divide circumference by 3·545.

To find the Area of a Circle:
Multiply circumference by one-quarter of the diameter; or
Multiply the square of diameter by 0·7854; or
Multiply the square of circumference by 0·07958; or
Multiply the square of $\frac{1}{2}$ diameter by 3·1416.

To find the Surface of a Sphere or Globe:
Multiply the diameter by the circumference; or
Multiply the square of diameter by 3·1416; or
Multiply four times the square of radius by 3·1416.

Cylinder.—To find the Area of Surface: Multiply the diameter by $3\frac{1}{7} \times$ length. Capacity $= 3\frac{1}{7} \times \text{radius}^2 \times$ height.

Values and Powers of π.—

$$\pi = 3{\cdot}1415926536, \text{ or } 3{\cdot}1416, \text{ or } \tfrac{22}{7}, \text{ or } 3\tfrac{1}{7};$$
$$\pi^2 = 9{\cdot}86965; \quad \sqrt{\pi} = 1{\cdot}772453;$$
$$\frac{1}{\pi} = 0{\cdot}31831; \quad \frac{\pi}{2} = 1{\cdot}570796; \quad \frac{\pi}{3} = 1{\cdot}047197.$$
$$1 \text{ radian} = \frac{180}{\pi} = 57{\cdot}2958 \text{ degrees.}$$

Powers and Roots of Useful Factors

n	$\frac{1}{n}$	n^2	n^3	$\sqrt{n}$	$\frac{1}{\sqrt{n}}$	$\sqrt[3]{n}$	$\frac{1}{\sqrt[3]{n}}$
π = 3·142	0·318	9·870	31·006	1·772	0·564	1·465	0·683
2π = 6·283	0·159	39·478	248·050	2·507	0·399	1·845	0·542
$\frac{\pi}{2}$ = 1·571	0·637	2·467	3·878	1·253	0·798	1·162	0·860
$\frac{\pi}{3}$ = 1·047	0·955	1·097	1·148	1·023	0·977	1·016	0·985
$\frac{4}{3}\pi$ = 4·189	0·239	17·546	73·496	2·047	0·489	1·612	0·622
$\frac{\pi}{4}$ = 0·785	1·274	0·617	0·484	0·886	1·128	0·923	1·084
$\frac{\pi}{6}$ = 0·524	1·910	0·274	0·144	0·724	1·382	0·806	1·241
π^2 = 9·870	0·101	97·409	961·390	3·142	0·318	2·145	0·466
π^3 = 31·006	0·032	961·390	29,809·910	5·568	1·796	3·142	0·318
$\frac{\pi}{32}$ = 0·098	10·186	0·0095	0·001	0·313	3·192	0·461	2·168
g = 32·2	0·031	1,036·84	33,386·24	5·674	0·176	3·181	0·314
$2g$ = 64·4	0·015	4,147·36	267,090	8·025	0·125	4·007	0·249

Fig. 25.—*In any right-angled triangle:*

$$\tan A = \frac{BC}{AC}, \quad \sin A = \frac{BC}{AB}$$

$$\cos A = \frac{AC}{AB}, \quad \cot A = \frac{AC}{BC}$$

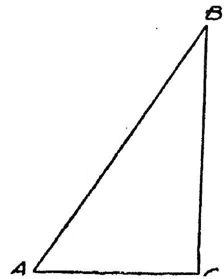


Fig. 25.

b

Fig. 26.

Fig. 26.—*In any right-angled triangle:*

$$a^2 = c^2 + b^2$$
$$c = \sqrt{a^2 - b^2}$$
$$b = \sqrt{a^2 - c^2}$$
$$a = \sqrt{b^2 + c^2}$$

In Fig. 28, *where the lengths of three sides only are known:*

$$\textit{area} = \sqrt{s(s-a)(s-b)(s-c)}$$

where $s = \dfrac{a + b + c}{2}$

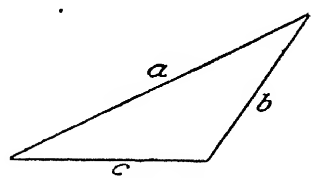


Fig. 28.

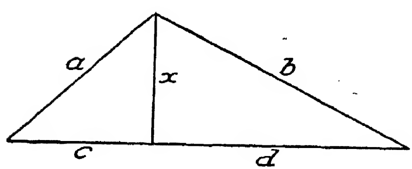


Fig. 27.

Fig. 27. $c + d : a + b :: b - a : d - c$

$$d = \frac{c + d}{2} + \frac{d - c}{2}$$
$$x = \sqrt{b^2 - d^2}$$

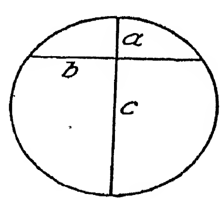


Fig. 29.—*In this diagram*

$$a : b :: b : c, \text{ or } \frac{b^2}{a} = c$$

Fig. 29.

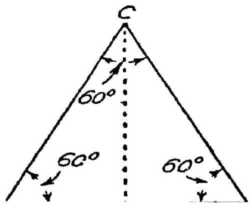


Fig. 30.—*In an equilateral triangle* ab = 1, *then* cd = $\sqrt{0{\cdot}75}$ = 0·866, *and* ad = 0·5; ab = 2, *then* cd = $\sqrt{3{\cdot}0}$ = 1·732, *and* ad = 1; cd = 1, *then* ac = 1·155 *and* ad = 0·577; cd = 0·5, then ac = 0·577 and ad = 0·288.

Fig. 31.—*In a right-angled triangle with two equal acute angles,* bc = ac.
bc = 1, *then* ab = $\sqrt{2}$ = 1·414;
ab = 1, *then* bc = $\sqrt{0{\cdot}5}$ = 0·707.

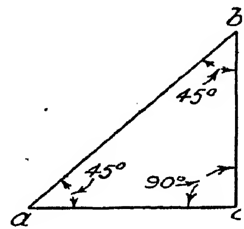


Fig. 31.

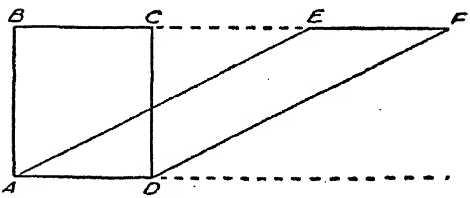


Fig. 32.

Fig. 32 *shows that parallelograms on the same base and between the same parallels are equal; thus ABCD = ADEF.*

Fig. 33 *demonstrates that triangles on the same base and between the same parallels are equal in area; thus ABC = ADC.*

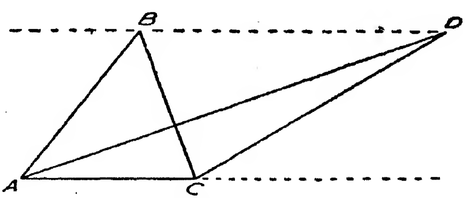


Fig. 33.

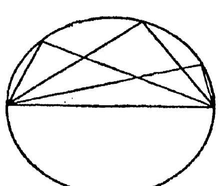


Fig. 34.—*All triangles constructed in a circle and having a diameter as a base are right-angled triangles.*

Fig. 34.

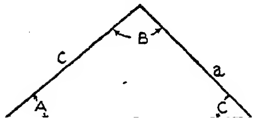


Fig. 35.—Diagram for Table A.

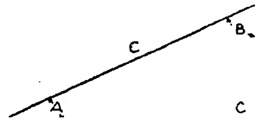


Fig. 36.—Diagram for Table B.

TABLE A
(*See Fig.* 35)

Parts Given.	*Parts to be Found.*	*Formulæ*
$a\ b\ c$	A	$\cos A = \dfrac{b^2 + c^2 - a^2}{2bc}$
$a\ b$ A	B	$\sin B = \dfrac{b \times \sin A}{a}$
$a\ b$ A	C	$C = 180° - (A + B)$
a A B	b	$b = \dfrac{a \times \sin B}{\sin A}$
a A B	c	$c = \dfrac{a \sin C}{\sin A} = \dfrac{a \sin (A + B)}{\sin A}$
$a\ b$ C	B	$B = 180° - (A + C)$

Trigonometrical Functions

RIGHT-ANGLED TRIANGLES
(*See Fig.* 36)

$\text{Sin } A = \dfrac{a}{c}$ $\qquad$ $\text{Sec } A = \dfrac{c}{b}$ $\qquad$ $\text{Tan } A = \dfrac{a}{b}$

$\text{Cos } A = \dfrac{b}{c}$ $\qquad$ $\text{Cosec } A = \dfrac{c}{a}$ $\qquad$ $\text{Cotan } A = \dfrac{b}{a}$

$\text{Versin } A = \dfrac{c - b}{}$ $\qquad$ $\text{Coversin } A = \dfrac{c - a}{}$

TABLE B

(*See Fig.* 36)

Parts Given	*Parts to be Found.*				
	A	*B*	*a*	*b*	*c*
a & c	$\sin A = \frac{a}{c}$	$\cos B = \frac{a}{c}$		$b = \sqrt{c^2 - a^2}$	
a & b	$\tan A = \frac{a}{b}$	$\cot B = \frac{a}{b}$			$c = \sqrt{a^2 + b^2}$
c & b	$\cos A = \frac{b}{c}$	$\sin B = \frac{b}{c}$	$a = \sqrt{c^2 - b^2}$		
A & a		$B = 90° - A$		$b = a \times \cot A$	$c = \frac{a}{\sin A}$
A & b		$B = 90° - A$	$a = b \times \tan A$		$c = \frac{b}{\cos A}$
A & c		$B = 90° - A$	$a = c \times \sin A$	$b = c \times \cos A$	

Trigonometrical Equivalents

Sine $= \sqrt{1 - \text{Cos}^2}$.
Sine $= 1 \div$ Cosec.
Sine $=$ Cos $\div$ Cotan.
Sine $=$ Tan $\div$ Sec.
Cosine $= \sqrt{1 - \text{Sin}^2}$.
Cosine $= 1 \div$ Sec.
Cosine $=$ Sin $\times$ Cotan.
Cosine $=$ Sin $\div$ Tan.
Secant $= 1 \div$ Cos.
Secant $=$ Tan $\div$ Sin.
Cosecant $= 1 \div$ Sin.
Tangent $= 1 \div$ Cotan.
Tangent $=$ Sin $\div$ Cos.
Cotangent $= 1 \div$ Tan.
Cotangent $=$ Cos $\div$ Sin.
Versine $= 1 -$ Cos.
Coversine $= 1 -$ Sin.
$1 =$ Tan $\times$ Cotan.
$1 = \text{Sin}^2 + \text{Cos}^2$.
$\text{Secant}^2 = 1 + \text{Tan}^2$.

METRIC SYSTEM

List of Prefixes

mega	means a million times.
kilo	means a thousand times.
hecto	means a hundred times.
deca	means ten times.
deci	means a tenth part of.
centi	means a hundredth part of.
milli	means a thousandth part of.
micro	means a millionth part of.

Square Measure

100 sq. metres	=	1 are.
10,000 sq. metres	=	1 hectare.

Weight

10 grammes	=	1 decagramme.
10 decagrammes	=	1 hectogramme.
10 hectogrammes	=	1 kilogramme.
1,000 kilogrammes	=	1 tonne.

Capacity

1 litre	=	1 cubic decimetre.
10 litres	=	1 decalitre.
10 decalitres	=	1 hectolitre.
10 hectolitres	=	1 kilolitre.

Length

10 millimetres	=	1 centimetre.
10 centimetres	=	1 decimetre.
10 decimetres	=	1 metre.
10 metres	=	1 decametre.
10 decametres	=	1 hectometre.
10 hectometres	=	1 kilometre.
10 kilometres	=	1 myriametre.

Linear Measure

1 inch	= 2·54 centimetres, or 25·4 millimetres.
1 foot	= 30·4799 centimetres, 304·799 millimetres, or 0·3047 metre.
1 yard	= 0·914399 metre.
1 mile	= 1·6093 kilometres = 5,280 feet.
1 millimetre	= 0·03937 inch.
1 centimetre	= 0·3937 inch.
1 decimetre	= 3·937 inches.
1 metre	= 39·370113 inches.
	3·28084 feet.
	1·093614 yards.
1 kilometre	0·62137 mile.
1 decametre (10 metres)	10·936 yards.

Metric Conversion Factors

To convert—

Millimetres to inches	× 0·03937 or ÷ 25·4
Centimetres to inches	× 0·3937 or ÷ 2·54
Metres to inches	× 39·37
Metres to feet	× 3·281
Metres to yards	× 1·094
Metres per second to feet per minute	× 197
Kilometres to miles	× 0·6214 or ÷ 1·6093
Kilometres to feet	× 3,280·8693
Square millimetres to square inches	× 0·00155 or ÷ 645·1
Square centimetres to square inches	× 0·155 or ÷ 6·451
Square metres to square feet	× 10·764
Square metres to square yards	× 1·2
Square kilometres to acres	× 247·1
Hectares to acres	× 2·471
Cubic centimetres to cubic inches	× 0·06 or ÷ 16·383
Cubic metres to cubic feet	× 35·315
Cubic metres to cubic yards	× 1·308
Cubic metres to gallons (231 cu. in.)	× 264·2
Litres to cubic inches	× 61·022
Litres to gallons	× 0·2642 or ÷ 3·78
Litres to cubic feet	÷ 28·316
Hectolitres to cubic feet	× 3·531
Hectolitres to bushels (2,150·42 cu. in	× 2·84
Hectolitres to cubic yards	× 0·131
Hectolitres to gallons	÷ 26·42
Grammes to ounces (avoirdupois)	× 0·035 or ÷ 28·35

To convert—

Grammes per cubic centimetre to pounds per cubic inch	÷ 27·7
Joules to foot-pounds . . .	× 0·7373
Kilogrammes to ounces . . .	× 35·3
Kilogrammes to pounds . . .	× 2·2046
Kilogrammes to tons . . .	× 0·001
Kilogrammes per square centimetre to pounds per square inch . . .	× 14·223
Kilogramme-metres to foot-pounds .	× 7·233
Kilogrammes per metre to pounds per foot	× 0·672
Kilogrammes per cubic metre to pounds per cubic foot	× 0·062
Kilogrammes per cheval to pounds per horse-power	× 2·235
Kilowatts to horse-power . . .	× 1·34
Watts to horse-power . . .	÷ 746
Watts to foot-pounds per second .	× 0·7373
Cheval vapeur to horse-power . .	× 0·9863
Gallons of water to pounds . .	× 10
Atmospheres to pounds per square inch	× 14·7

Other Metric-to-English Conversion Factors

Pounds per cubic foot.	×	16·020	= kilos per cubic metre.
Tons per cubic yard .	×	1·329	= tonnes per cubic metre
Grains per gallon .	×	0·01426	= grammes per litre.
Pounds per gallon .	×	0·09983	= kilos per litre.
Gallons per square foot	×	48·905	= litres per square metre.
Inch-tons . . .	×	25·8	= kilogrammetres.
Foot-pounds . .	×	0·1382	= kilogrammetres.
Foot-tons . . .	×	0·309	= tonne-metres.
Horse-power . .	×	1·0139	= force de cheval.
Pounds per H.P. .	×	0·477	= kilos per cheval.
Square feet per H.P. .	×	0·0916	= square metres per cheval
Cubic feet per H.P. .	×	0·0279	= cubic metres per cheval
Heat units . . .	×	0·252	= calories.
Heat units per square foot . . .	×	2·713	= calories per square metre.

METRICAL TO ENGLISH CONVERSIONS

Kilos per lineal metre .	× 0·672	= pounds per lineal foot.
Kilos per lineal metre .	× 2·016	= pounds per lineal yard.
Kilos per lineal metre .	× 0·0003	= tons per lineal foot.
Kilos per lineal metre .	× 0·0009	= tons per lineal yard.
Kilos per kilometre . .	× 3·548	= pounds per mile.
Kilos per square centimetre	× 14·223	= pounds per square inch.
Kilos per square millimetre	× 0·635	= tons per square inch.
Kilos per square metre .	× 0·2048	= pounds per square foot.
Tonnes per square metre .	× 0·0914	= tons per square foot.
Tonnes per square metre .	× 0·823	= tons per square yard.
Kilos per cubic metre .	× 1·686	= pounds per cubic yard.
Kilos per cubic metre .	× 0·0624	= pounds per cubic foot.
Tonnes per cubic metre .	× 0·752	= tons per cubic yard.
Grammes per litre . .	× 70·12	= grains per gallon.
Kilos per litre . . .	× 10·438	= pounds per gallon.
Litres per square metre .	× 0·0204	= gallons per square foot.
Kilogrammetres . .	× 7·233	= foot-pounds.
Kilogrammetres . .	× 0·0387	= inch-tons.
Tonne-metres . . .	× 3·23	= foot-tons.
Force de cheval . .	× 0·9863	= horse-power.
Kilos per cheval . .	× 2·235	= pounds per H.P.
Square metres per cheval .	× 10·913	= square feet per H.P.
Cubic metres per cheval .	× 35·806	= cubic feet per H.P.
Calories	× 3·968	= heat units.
Calories per square metre .	× 0·369	= heat units per square foot.

ENGLISH TO METRICAL CONVERSIONS

Pounds per lineal foot.	×	= kilos per lineal metre.
Pounds per lineal yard	× 0·496	= kilos per lineal metre.
Tons per lineal foot .	× 3333·33	= kilos per lineal metre.
Tons per lineal yard .	× 1111·11	= kilos per lineal metre.
Pounds per mile . .	× 0·2818	= kilos per kilometre.
Pounds per square inch	× 0·0703	= kilos per square centimetre.
Tons per square inch .	× 1·575	= kilos per square millimetre.
Pounds per square foot	× 4·883	= kilos per square metre.
Tons per square foot .	× 10·936	= tonnes per square metre.
Tons per square yard .	× 1·215	= tonnes per square metre.
Pounds per cubic yard.	× 0·5933	= kilos per cubic metre.

Equivalents of Imperial and Metric Weights and Measures

Linear Measure

Imperial		Metric	
1 Inch	= 25·400 Millimetres.	1 Millimetre (mm.) ($\frac{1}{1000}$ m.)	= 0·03937 Inch.
1 Foot	= 0·30480 Metre.	1 Centimetre ($\frac{1}{100}$ m.)	= 0·3937 „
1 Yard	= **0·914399 Metre.**	1 Decimetre ($\frac{1}{10}$ m.)	= 3·937 Inches.
1 Fathom	= 1·8288 Metres.	**1 Metre (m.)**	= **39·370113 Inches.** **3·280843 Feet.** **1·0936143 Yards.**
1 Pole	= 5·0292 „	1 Decametre (10 m.)	= 10·936 Yards.
1 Chain	= 20·1168 „	1 Kilometre (1,000 m.)	= 0·62137 Mile.
1 Furlong	= 201·168 „		
1 Mile	= 1·6093 Kilometres.		

Square Measure

Imperial		Metric	
1 Square Inch	= 6·4516 Square Centimetres.	1 Square Centimetre	= 0·15500 Square Inch.
1 Square Foot	= 9·2903 Square Decimetres.	1 Square Decimetre	= 15·500 Square Inches.
1 Square Yard	= 0·836126 Square Metre.	1 Square Metre	= 10·7639 Square Feet. 1·1960 Square Yards.
1 Rood	= 10·117 Ares.	1 Are	= 119·60 „ „
1 Acre	= 0·40468 Hectare.	1 Hectare	= 2·4711 Acres.
1 Square Mile	= 259·00 Hectares.		

Cubic Measurement

Imperial		Metric	
1 Cubic Inch	= 16·387 Cubic Centimetres.	1 Cubic Centimetre	= 0·0610 Cubic Inches.
1 Cubic Foot	= 0·028317 Cubic Metre.	1 Cubic Decimetre (c.d.)	= 61·024 Cubic Inches.
1 Cubic Yard	= 0·764553 „ „	1 Cubic Metre	= 35·3148 Cubic Feet. 1·307954 Cubic Yards.

Measure of Capacity

Imperial		Metric	
1 Pint . . =	0·568 Litre.	1 Centilitre ($\frac{1}{100}$ litre) =	0·070 Gill.
1 Quart . . =	1·136 Litres.	1 Decilitre ($\frac{1}{10}$ litre) . =	0·176 Pint.
1 Gallon . . =	**4·5459631 Litre.**	**1 Litre . . . =**	**1·75980 Pints.**

Weight

Avoirdupois			*Avoirdupois*
1 Grain . . =	0·0648 Gramme.	1 Milligramme ($\frac{1}{1000}$ grm.) . . . =	0·015 Grain.
1 Dram . . =	1·772 Grammes.	1 Centigramme ($\frac{1}{100}$ grm.) =	0·154 ,,
1 Ounce . . =	28·350 ,,	1 Gramme (1 grm.) . =	15·432 ,,
1 Pound (7,000 Grains) . =	**0·45359243 Kilogramme.**	**1 Kilogramme (1,000 grm.) . . . . =**	**2·2046223 Lb. or 15,432·3564 Grains.**
1 Hundredweight =	50·80 Kilogramme. 0·5080 Quintal.	1 Quintal (100 kilog.) =	1·968 Cwt.
1 Ton . . =	1·0160 Tonnes or 1,016 Kilogrammes.	1 Tonne (1,000 kilog.) =	0·9842 Ton.
1 Grain (Troy) . =	0·0648 Gramme.	1 Gramme (1 grm.) . . =	0·03215 Oz. Troy. 15·432 Grains.
1 Troy Ounce . =	31·1035 Grammes.		

Pressure

pound per square inch = 144 pounds per square foot, which = 0·068 atmosphere = 2·042 inches mercury at 62° F. = 27·7 inches water at 62° F. = 2·31 feet water at 62° F.

1 inch mercury at 62° F. = 1·132 feet of water = 13·58 inches water = 0·491 pounds per square inch.

1 atmosphere = 30 inches mercury at 62° F. = 14·7 pounds per square inch = 2,116·3 pounds per square foot = 33·95 feet of water at 62° F.

1 foot of water at 62° F. = 62·355 pounds per square foot = 0·433 pounds per square inch.

ENGLISH WEIGHTS AND MEASURES

Long Measure

4 inches	= 1 hand.
12 inches (in.)	= 1 foot (ft.).
3 feet	= 1 yard (yd.).
$5\frac{1}{2}$ y	= 1 rod, pole, *or* perch.
40 poles (220 yards)	= 1 furlong (furl.).
8 furlongs (1,760 yards)	= 1 mile (m.).
3 miles	= 1 league.
1 chain	= 100 links (22 yards).
10 chains	= 1 furlong.
6 feet	= 1 fathom.
6,080·2 feet, *or* 1·1516 statute miles	= 1 nautical mile (knot).

Area (*Square Measure*)

144 square inches	= 1 square foot.
9 square feet	= 1 square yard.
$30\frac{1}{4}$ square yards	= 1 square pole.
40 square poles	= 1 rood.
4 roods	= 1 acre (4,840 square yards).
640 acres	= 1 square mile.

Measures of Volume and Capacity (*Cubic Measure*)

1,728 cubic inches	= 1 cubic foot.
27 cubic feet	= 1 cubic yard.
1 marine ton	= 40 cubic feet.
1 stack	= 108 cubic feet.
1 cord	= 128 cubic feet.

Measure of Capacity (*Liquid or Dry Measure*)

4 gills	= 1 pint.
2 pints	= 1 quart.
2 quarts	= 1 pottle.
2 pottles	= 1 gallon.
4 quarts	= 1 gallon.
2 gallons	= 1 peck.
4 pecks	= 1 bushel.
3 bushels	= 1 bag.
4 bushels	= 1 coomb.
8 bushels	= 1 quarter.
12 bags	= 1 chauldron.
5 quarters	= 1 load *or* wey.
2 loads *or* weys	= 1 last.

Wine Measure

4 gills	= 1 pint.
2 pints	= 1 quart.
4 quarts	= 1 gallon.
10 gallons	= 1 anker.
18 gallons	= 1 runlet or rundlet.
31½ gallons	= 1 barrel.
42 gallons	= 1 tierce.
63 gallons	= 1 hogshead.
2 tierces	= 1 puncheon.
1½ puncheons	= 1 pipe *or* butt.
2 pipes	= 1 tun.

Ale and Beer Measure

4 gills	= 1 pint.
2 pints	= 1 quart.
4 quarts	= 1 gallon.
9 gallons	= 1 firkin.
2 firkins	= 1 kilderkin.
2 kilderkins	= 1 barrel.
1½ barrels	= 1 hogshead.
1⅓ hogsheads	= 1 puncheon.
1½ puncheons *or* 2 hogsheads	= 1 butt *or* pipe.
2 pipes	= 1 tun.

Avoirdupois Weight

27·34375 grains	= 1 dram.
16 drams	= 1 ounce.
16 ounces	= 1 pound (lb.).
14 pounds	= 1 stone.
2 stone (28 lb.)	= 1 quarter.
4 quarters	= 1 hundredweight (cwt.)
20 cwt.	= 1 ton.
100 lb.	= 1 cental.

Apothecaries' Weight

20 grains or minims	= 1 scruple.
3 scruples	= 1 drachm.
8 drachms	= 1 ounce.
12 ounces	= 1 pound.

Apothecaries' Fluid Measure

60 minims	= 1 fluid drachm.
8 drachms	= 1 fluid ounce.
20 ounces	= 1 pint (pt. or O = Octarius).
8 pints	= 1 gallon (gal., C., or Cong. = Congius).

Diamond and Pearl Weight

3·17 grains	= 1 carat, *or*
4 pearl grains	= 1 carat.
151½ carats	= 1 ounce (troy).

Paper Measure

24 sheets	= 1 quire.
20 quires	= 1 ream.
2 reams	= 1 bundle.
10 reams	= 1 bale.

Troy Weight

3·17 grains	= 1 carat.
24 grains	= 1 pennyweight (dwt.).
20 pennyweights	= 1 ounce.
12 ounces	= 1 pound.
1 pound	= 5,760 grains.
1 pound (avoir.)	= 7,000 grains.

MECHANICAL DRAWING

The ability to produce a good drawing depends largely upon the condition of the drawing instruments and the observance of very definite rules regarding their treatment and usage.

All mathematical or drawing instruments worthy of the name are fitted with needle points. These points are made from ordinary sewing needles of such a diameter as will fill exactly the holes provided to receive them. If the case of instruments includes a pricker, the needle intended for a compass should be placed in the pricker with a good length projecting, the pointed end laid at a very fine angle on an oilstone, and rubbed lightly backwards and forwards, at the same time revolving it. Fig. 37 shows the comparative forms of the needle point before and after this treatment. All the needles in the compasses and spring bows should be given a very fine point. Dividers do not matter so much, although it is an advantage to have them also fairly sharp.

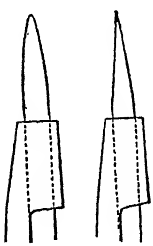


Fig. 37.—Needle points.

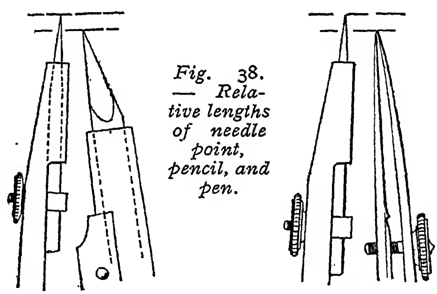


Fig. 38.—Relative lengths of needle point, pencil, and pen.

The next matter is that of the relative lengths of the needle and pen and pencil points. This is shown in Fig. 38. To adjust the lengths, the pencil or the pen nib should be brought close to the needle by closing the compass, and the needle be allowed to project beyond the pencil or pen, an amount just sufficient to enable it to enter the paper. Usually $\frac{1}{32}$ in. or at the most $\frac{3}{64}$ in. is enough. With most good instruments the end of the electrum in which the needle fits provides a stop to prevent the needle entering too deeply.

Pencil and Pen Points.—Many draughtsmen, for straight drawing, use a pencil sharpened to a chisel edge, and whether you

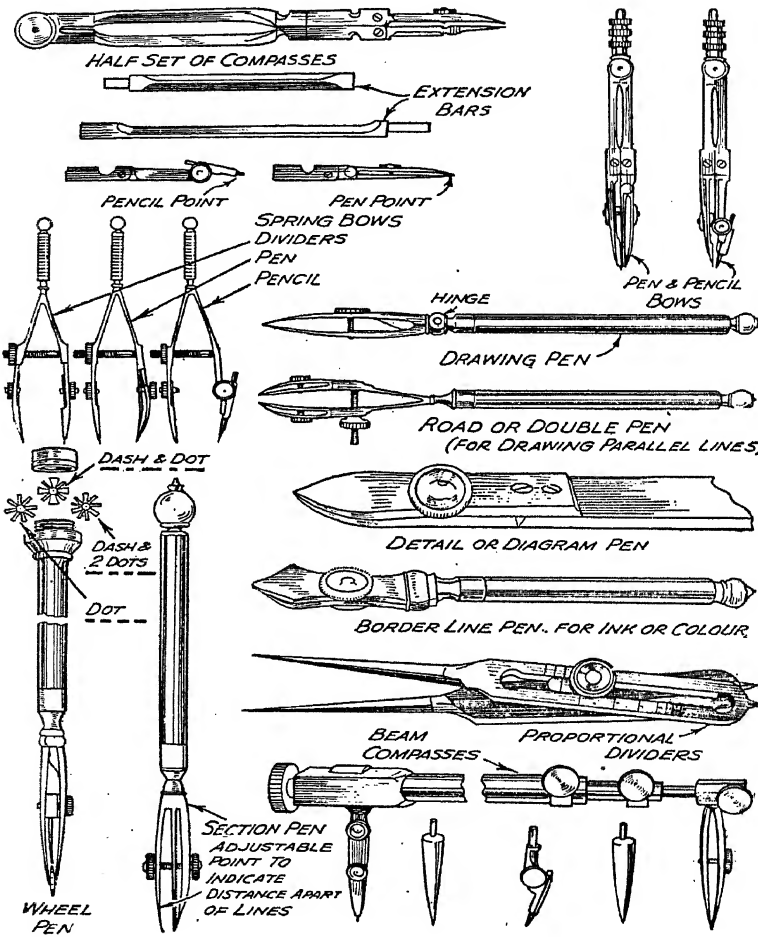


Fig. 39.—*Various drawing instruments.*

use such chisel edge or not on your ordinary pencils, you should certainly do so in your compasses. It will be found that the best grade for general work is 1H. Fig. 40 illustrates the shape to be given to the pencil, which shape is best obtained by using a small dead-smooth file. It is far quicker and more reliable than using a penknife. It seems a remarkable thing that the pen points of most instruments, even of the best English make, have, when they are purchased, the two nibs much too curved, or, if not both of them, the outermost next to the milled knob, as at A in Fig. 41. For rough work or heavy drawing this does not matter so much, but it is impossible to draw very fine lines with such a pen when it is fully charged with ink. This criticism concerns, not only the compasses, but the ruling pens. If one charges such a pen with ink and commences to draw, the lines will become gradually thinner as the ink flows out, and, if care is not taken,

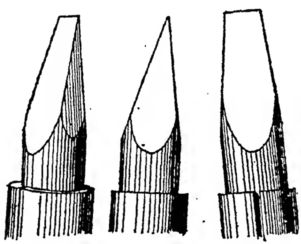


Fig. 40.—Pencil points.

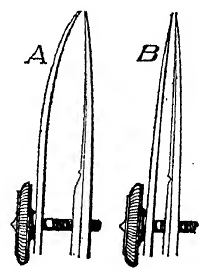
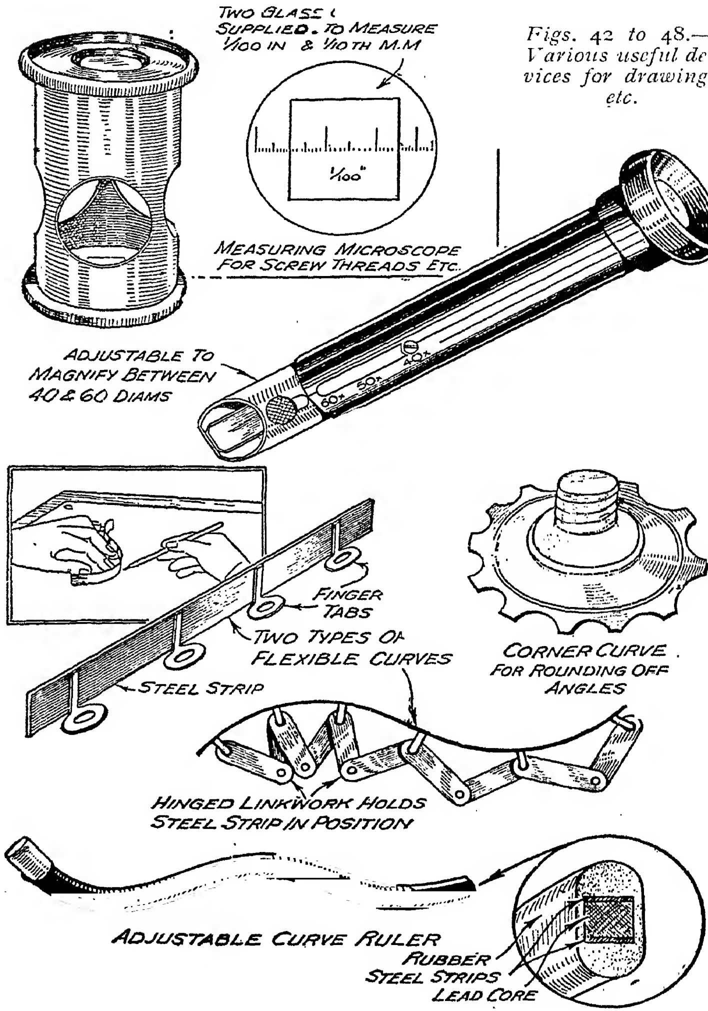


Fig. 41.—Pen points.

and too much ink is placed in the nibs, when the pen or compass is tilted vertically over the paper the whole lot will drop out with, of course, disastrous results. Another effect from overcharging with ink is that at the ends of the lines, both commencement and finish, there will certainly be a thickening up and probably a blob, as at A, Fig. 49. In all cases where thick lines are required, it is better to draw two lines and let them run one into the other, as at B.

A Simple Remedy.—The remedy is to open the nibs and straighten them to a considerable extent. This must be done very carefully, for if the steel is highly tempered it may be fractured in the attempt to straighten it. The safest plan is to draw the temper first, then straighten until the two nibs are nearly parallel. as shown at B, Fig. 41, and then reharden and set the two nib



Figs. 42 to 48.—Various useful devices for drawing, etc.

together and rub them down on the stone, on the outside surfaces only. Those who are not used to hardening and tempering should refer to the section on the subject. In setting the nibs the grinding on the oilstone should be done in such a way that the sides and extreme points of both nibs have exactly the same thickness at their edges, and that thickness should be practically

Fig. 49.—Drawing heavy lines.

nil; that is to say, the nibs should have very nearly a cutting edge. It is only by thus setting them that the nibs can be expected to draw the finest of hair lines.

It may be worth while explaining that the reason why the bow-shaped nibs will not hold the ink is that the weight of the fluid tends to overcome capillary attraction, whereas in closed or parallel nibs capillary attraction is practically constant and the same, whether the pen be full of ink or nearly empty.

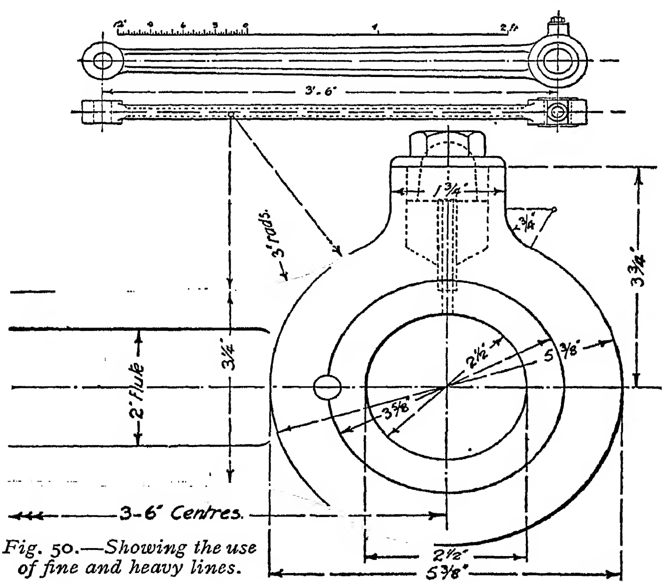
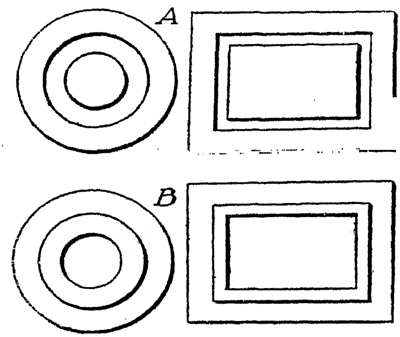


Fig. 50.—Showing the use of fine and heavy lines.

Drawing Fine Lines.—Waterproof ink is inclined to clog, especially in hot or dry weather. The secret lies in setting the nibs so that they almost, but not quite, cut the paper. When drawing, press very lightly with the pen, and above all keep the pen clean. This matter of cleanliness is very important indeed : lack of it is the source of most drawing troubles. Keep by you on the drawing-board a few square inches of linen, and make a rule each time before refilling the pen to wipe it out, if necessary dipping it in water before wiping. If you have occasion to stop drawing, even for a minute or two, wipe out the pen. It is undesirable to let the ink become dry between the nibs.

Thick and Thin Lines.—Quite a number of draughtsmen admire drawings made with heavy, bold lines, but some of them forget that both heavy and fine lines have their particular uses. In a general way, workshop drawings made to full size and fully dimensioned, especially when they are to be blue-printed, should be heavily drawn, but small-scale drawings and general arrangements, where many measurements have to be taken off with dividers and scale, should always be finely drawn, for it is obvious that accurate measurements between two lines cannot be taken when the lines themselves have a definite thickness. Fig. 50



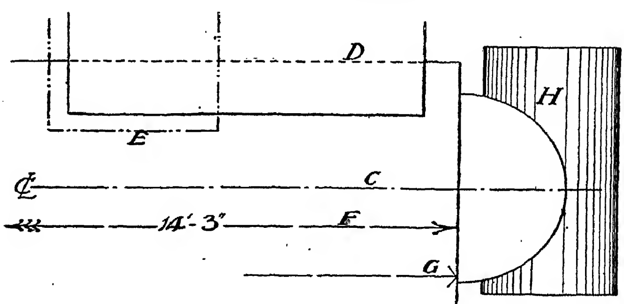


Fig. 51.—*Back lining construction lines and shading.*

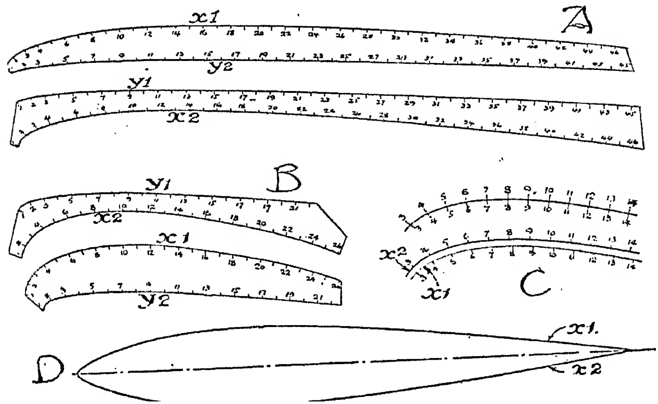


Fig. 52.—Types of calibrated curves that overcome a number of difficulties met with on the drawing-board.

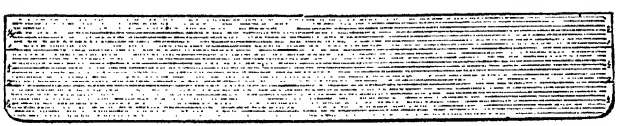


Fig. 53.—A device for drawing parallel lines.

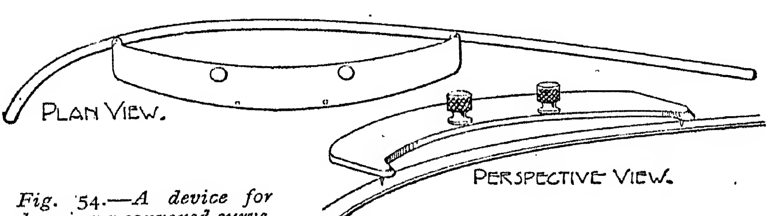


Fig. 54.—A device for drawing a convexed curve.

illustrates this point. By means of the scale, every measurement of the connecting rod shown can be taken off, whilst the big end, drawn below the complete rod, is big enough to fully dimension, and therefore can be boldly inked in.

Back Lining.—With the introduction of what is known as "back lining," we begin to enter the field of drawing in relief. This matter of relief is seldom carried beyond the stage of the simple back lining, but even this can be made very effective. The upper diagram of Fig. 51 is intended to illustrate this. At both A and B we have exactly the same lines drawn, three circles and three rectangles in each case symmetrically arranged one inside the other, but they are differently back lined. Referring to the circles only for convenience, the two inner circles at A make it appear that the space between them is recessed, whilst at B the same two rings make the space appear to stand clear. This also applies to the rectangles, the recessing and relief being in the same order.

Construction Lines.—In mechanical drawing, certain lines have been adopted as standard for indicating definite meanings. The drawing of the object represented, which is intended to be visible, is, of course, shown in full and complete lines. Centre lines of symmetrical objects are drawn with one dot and one dash as at C, Fig. 51, and sometimes marked with a monogram CL. The outline of the portion of an object which passes behind another object is shown by short dots, as D. If the object is in section and it is desired to show some portion of it which is removed by the sectioning, that portion is indicated as at E with a dash and two dots. Thus, suppose we were drawing a locomotive in section looking towards the right-hand side, and we wished to indicate the position of, say, an injector which is on the left-hand side, we should show it by this dash-and-two-dot line.

Dimension lines are shown as at F by a series of dashes with no dots. Dimension figures should be placed as nearly as may be convenient in the middle of the line, and the lines should terminate with arrow heads. Some inexperienced draughtsmen make their arrow heads after the manner shown at G; this looks bad, and indicates the novice. The shape shown at the right-hand end of the line F is much neater and occupies less room. Where a dimension extends to a point beyond the limits of the drawing, it is usual to draw three arrow heads one behind the other in the manner shown.

The shading of round objects in ordinary mechanical drawing is added to Fig. 51 at H, approximately the same number of

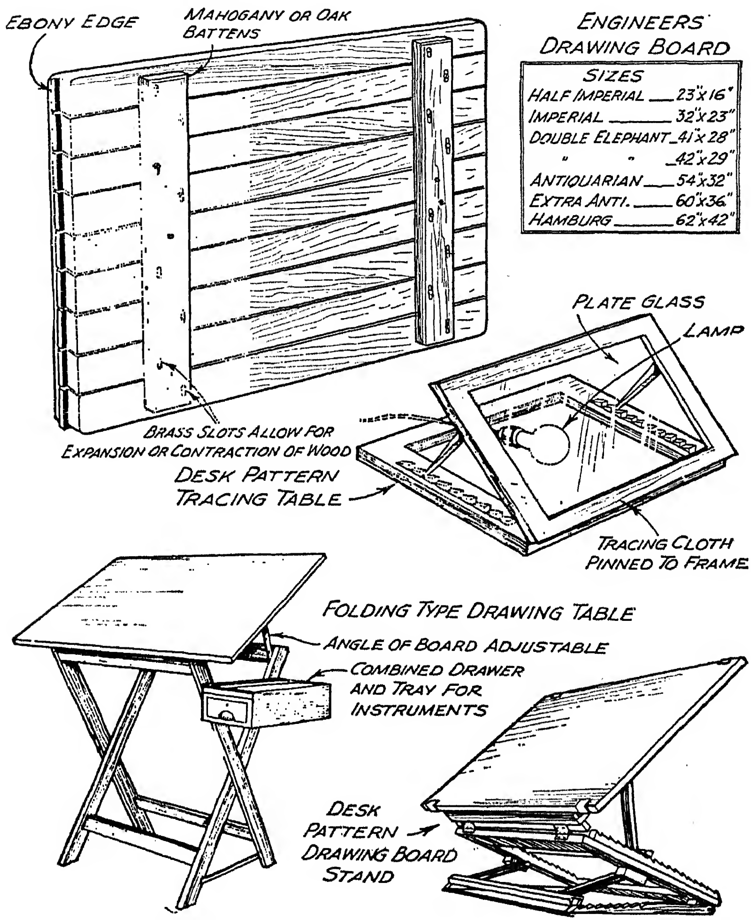


Fig. 55.—Drawing-boards, tables, etc.

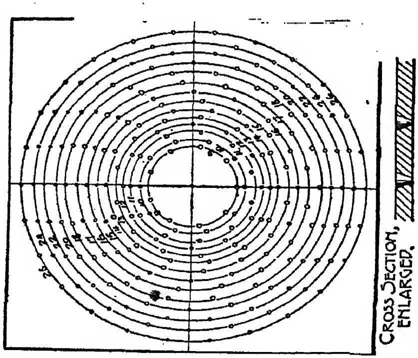
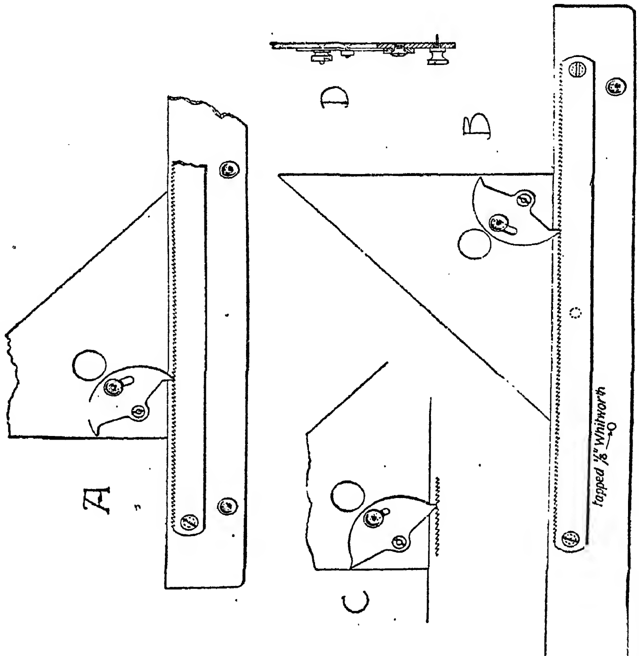


Fig. 57.—This instrument, made of celluloid, facilitates the dividing up of circles in a drawing.



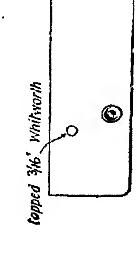


Fig. 56.—Another ingenious device which has a number of uses, including correct spacing of section lines (hatching).

lines being drawn on each side of the centre, which lines become closer together as they reach the limits of the diameter.

Greater Relief Effect.—We now come to a class of drawing which goes rather beyond the limits of ordinary mechanical drawing ; in fact, although the outline of the object may be of a mechanical nature, the result may be termed semi-pictorial. The process includes tone shading by hatching, the projection of definite shadows from the portion in relief, and the representation of high-lights, shadow, and reflected lights on round objects. Fig. 58 illustrates at A the method of treating a cylindrical object. Here it will be seen how the treatment differs from H in Fig. 51. The high-light, that is to say, the point where the light is striking the cylinder, is where we have placed the letter A, whilst on the opposite side of the cylinder the deepest shadow is reduced by some light being reflected upon it.

At B we have drawn an imaginary bit of steel-plate structural work having rivets, the ends of bolts with nuts, and a tie rod with a turnbuckle. The making of drawings of this class calls for not only a definite consideration of the angle at which the light is striking, but the amount of projection of one part beyond another ; thus the plate holding the rivets is standing out clear of the main plate by a distance considerably greater than the height of the hexagon nuts. This is evidenced by the respective length of the shadows cast.

Some little practice is required in ruling the vertical hatching. It does not follow, by the way, that the hatching need be vertical. Horizontal lining is equally effective and frequently in combination with vertical, and cross-hatching is permissible to give a greater depth of tone. The spacing should be perfectly accurate, and that is why I say that some little practice is required, for

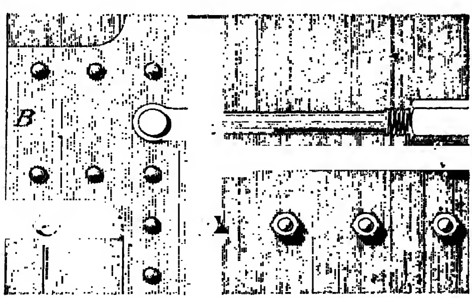


Fig. 58.—Shading and flat toning.

it will be obvious that the lines must all be quite uniform in thickness and spaced exactly the same distance apart. It is particu-

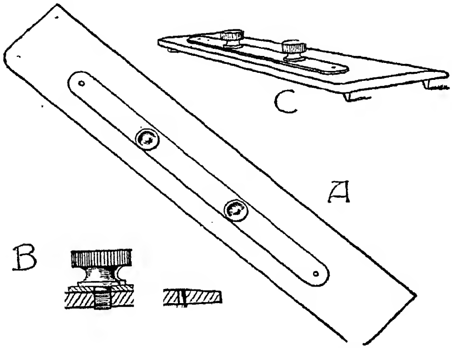


Fig. 59.—*A bridge rule for drawing lines without smudging the previous lines drawn.*

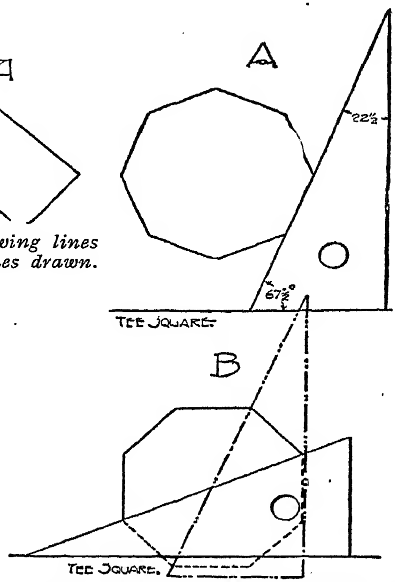


Fig. 60.—*A set square for drawing the sides of an octagon, at various diagonals.*

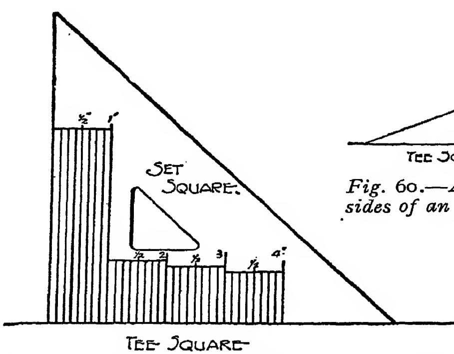


Fig. 61.—*A useful addition to an ordinary celluloid set square.*

larly in doing such work as this that fine setting of the pen and cleanliness in working are called for.

PRINCIPLES OF MECHANICAL DRAWING

The art of making mechanical drawings lies in correctly depicting an object in such a manner that a workman, or body of men, may make that object and make it exactly to such a form and dimension as may be predetermined by its designer.

A mechanical drawing may take any form and degree of completeness: from a rough freehand sketch, with dimensions figured in, to a carefully drawn general arrangement, showing every detail of the object.

Rough and Finished Drawings.—Whether it be a rough sketch or an accurately made drawing, it must convey every bit of information needed by the mechanic who is to construct the

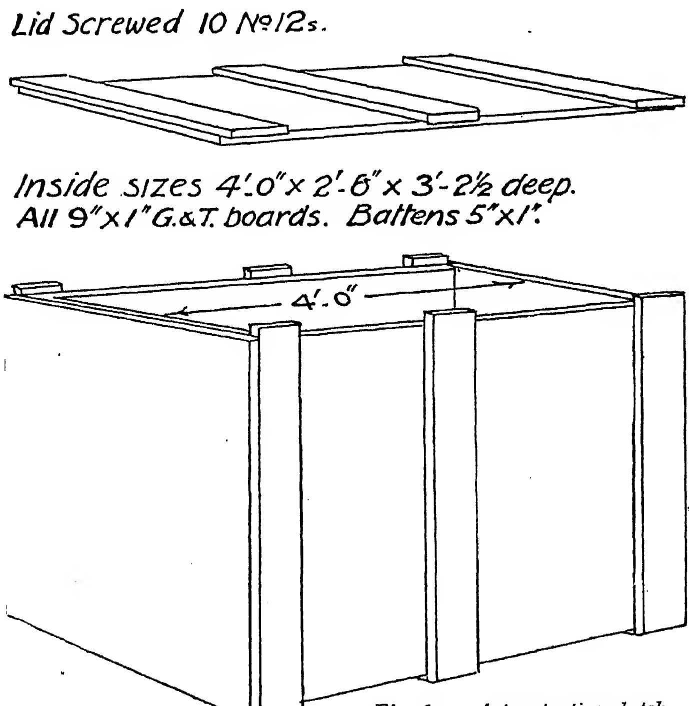


Fig. 62.—A perspective sketch.

object. (The word "mechanic" here refers to all such artisans as engineers, pattern makers, builders and joiners, etc.) From this it will be seen that particular needs call for particular methods of delineating the object, according to the amount of detail in it, thus: to enable a woodworker to make a packing case for some particular purpose, a rough sketch only is required, such sketch showing where the lid shall be and any battens required, with, of course, the figured sizes: inside length, breadth, depth, and thickness of stuff. At the other end of the scale of elaboration we have the complete set of "general arrangement" drawings for some intricate, made-up-of-many-parts machine, such as a locomotive. General arrangement drawings consist of a number of views, so made that they show every part and detail of the machine, both inside and out.

In the case of large, intricate machines, the general arrangements are intended to show more particularly—as the name implies—not so much how the parts are to be made, but how they are to be assembled, and separate drawings are prepared of each part or detail for the makers of the parts to work from. Then, in the case of a locomotive, the measurements figured upon the general arrangement need only be those which the detail parts could not give. Such, for instance, as the height of boiler centre above rails, wheelbase, length overall, etc.

In the case of model making, a general arrangement usually serves for all requirements, and only a few, if any, details are drawn separately.

Perspective Drawings.—Perspective, or pictorial, drawing is made very little use of by the mechanical draughtsman; for, except in the case of very simple objects, where sectional drawings are needless, it is not required.

Suppose, however, that such a simple thing as the packing case before mentioned had to be made, then the easiest way to convey to the carpenter one's ideas as to how it should be made is by means of a perspective view, for this is the quickest and easiest to prepare. Such a sketch is shown in Fig. 62.

Obviously such a drawing need not be made to scale, and the workman will depend solely upon the figured measurements for making it of the correct proportions and size.

It will not need much consideration to think of dozens of other such simple objects which have to be made from drawings but in which a perspective view may not meet the case or may better be shown by more strictly mechanical drawing. Let us take, for example, a kitchen table and illustrate it in Fig. 64; here we need two elevations, one of the side A, and one of the end B, and, in

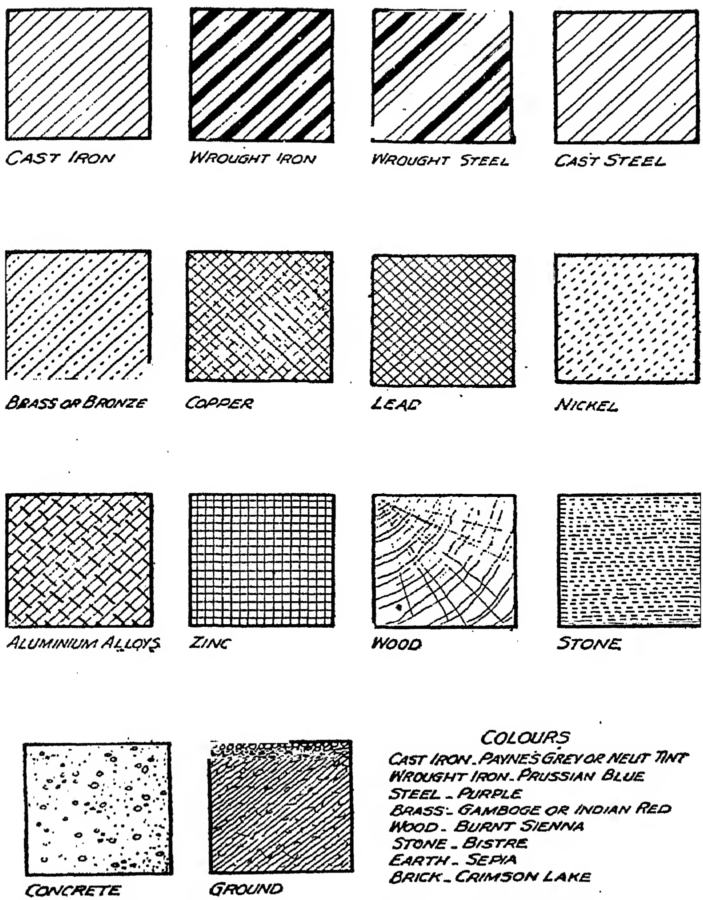


Fig. 63.—Some conventional methods of cross-hatching various materials in sectional drawings. Most drawing offices now adopt the practice set forth in "British Standard Drawing Office Practice" (B.S.I. Booklet No. 308/1927).

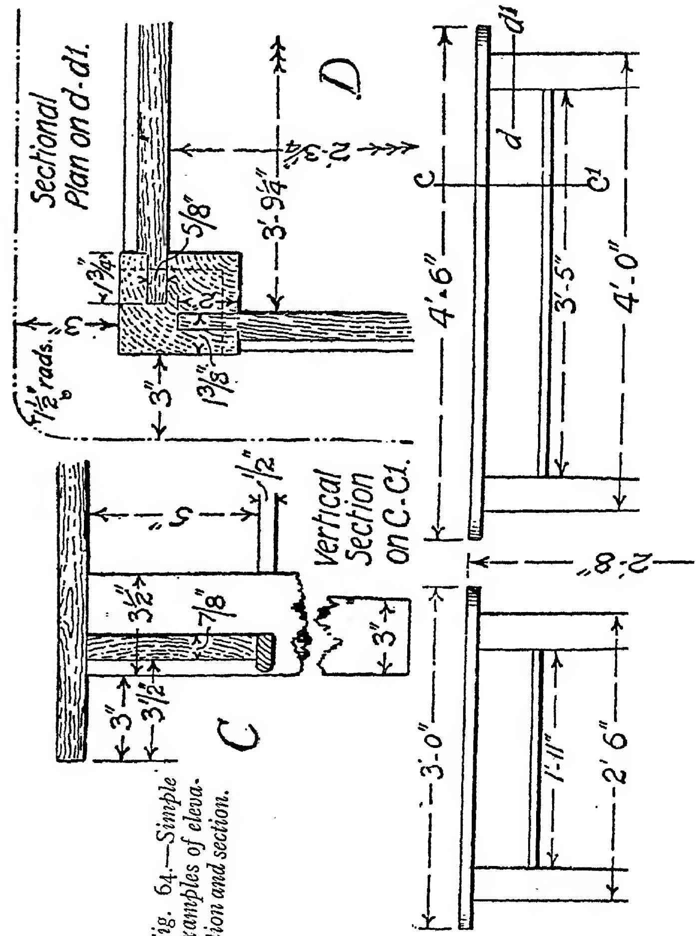


Fig. 64.—Simple examples of elevation and section.

addition, a detail cross-section taken vertically through one rail, and a part of the top as at C, and a horizontal cross-section D through a leg and two rails to show the mortises and tenons.

Sectional Drawings.—In these two sections measurements are figured and forms are explained which obviously could not be conveyed by a perspective view.

"But what is meant by a section?" some people may ask; "and how can it be said that the sketch C indicates the rail and part of the top?" Well, the answer is that "Section" means Cut. A glance at the side elevation will show a line drawn across one edge of the table, marked "C, C." Suppose now we were to take a handsaw and cut the table into two halves, turn the cut

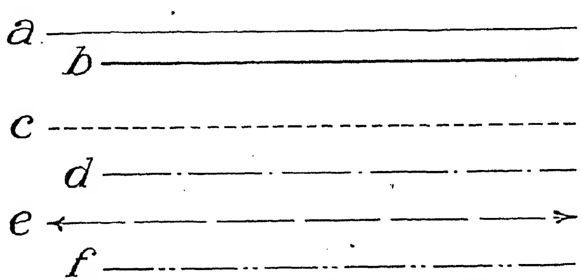


Fig. 65.—Lines used in mechanical drawings

edge of the wood towards our faces, and look at it; we should see exactly the shape of the end view of the wood which is drawn at C. That is just what is meant when a drawing is marked "Section." It means that you have to imagine the object cut through to reveal what is otherwise hidden.

Sometimes we see on a drawing the words "longitudinal section," "cross-section," and on certain other drawings "sectional plan." The adjective in all cases indicates the direction in which a cut is supposed to be made. The first two are vertical cuts taken lengthwise and across respectively, whilst the third will be a horizontal sectioning, and we are then supposed to be looking down upon what is left after the cut is made. In all cases of sectioning we have to imagine that one half, or part, of the object is taken right away, leaving the other part to be viewed. Examples of these three directions of sectioning will be given later, together with external views or "Elevations" and "Plans" from various aspects; but first it will be desirable to explain the meaning conveyed by the various kinds of line used in mechanical

drawings. Such lines are by no means all continuous and unbroken.

Lines used in Drawings.—First in importance is, of course, the unbroken or full line which indicates the outline of the actual object. This we will include for the sake of completeness in Fig. 65, where *a* indicates the line usually used in simple drawings and those made to small scales, as well as in most general arrangements where there is a lot of detail.

In the drawings of separate parts, however, where the scale used is larger and more simplicity and space are available, the lines of the under side and the right-hand side are drawn much heavier as at *b* in order to represent shadow and so give an effect of relief. Where this scheme is adopted, the drawing is said to be back lined. The sketches made in Fig. 66 represent at A a back-lined rectangle and at B a disk. In both cases you will see how an

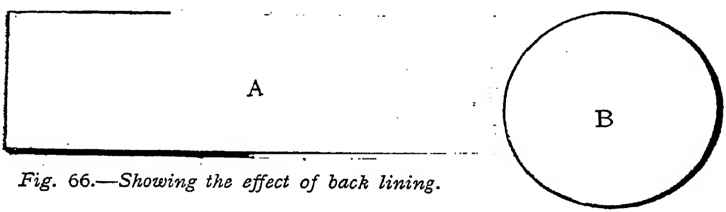


Fig. 66.—Showing the effect of back lining.

appearance of solidity is given, as though the objects drawn are standing out from the paper.

The two of next importance are the short-dotted line *c* and the dot-and-dash line *d*, Fig. 65. The first of these is used to indicate parts which are hidden behind some other larger part, or the continuation of a part beyond the point where it can be seen. Short-dotted lines may occur in a pure elevation drawing; that is to say, in a drawing which purports to be an outside view. Indeed, it is possible to make an external elevation, and show the whole of the interior details by means of such dotted lines, though this is seldom done, because such interior is better shown by means of a section.

Centre Lines.—The dot-and-dash *d* is used for what is known as centre lines. Suppose we have a cylindrical object, or any other thing in which certain portions are balanced about a definite centre, then that centre is drawn by means of a dot-and-dash line.

Dimension Lines.—Next we have the dash line, shown at *e* in Fig. 65. This is used, with an arrow head at each end, for

dimensions. In all cases the arrow heads will just touch other lines, and the figure written in the middle of the dash line is the measurement between those lines.

There remains one other: the dash-and-two-dot line. This is more seldom used than any other, because few drawings call for its introduction. It is used thus: suppose we have a sectional drawing of an object in which the two sides in respect of details are not alike. Being a section, one half of the object is cut away and is supposed to be removed. This being the case, some details are removed also, and yet it is necessary to show those details. In a section there may be details on the far side—the outside—or the portion which is drawn and not removed, and such details are indicated by short-dotted lines. How, then, will it be possible to show details which are taken away with the removed side? Well, the difficulty is overcome by adopting a different system or

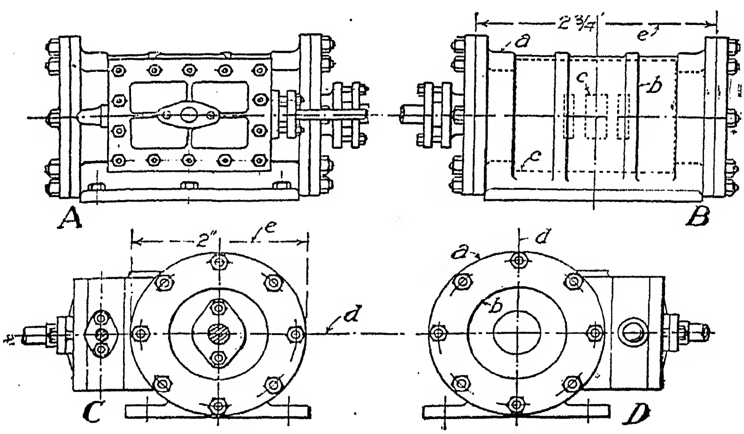


Fig. 67.—*Side and end elevation.*

type of line, and the one which has become recognised is the dash-and-two-dot. With this, then, all parts which have been removed in sectioning are drawn.

Feet and Inches.—In all mechanical drawings feet are indicated by one stroke against a figure, thus: ′ and inches by two strokes ″.

Referring again to centre lines, many machines and other constructions in metal and in wood have more than one line about which the object is balanced. Very frequently there is a cross-centre line as well as a longitudinal one, and sometimes there are centre lines making all, or any, angles with the main one and, it may be, in an altogether different plane. Centre lines are principally used for the purpose of indicating a point from which measurements are to be taken.

It is now intended to show some typical examples to serve as additional explanation of what has been written, so it is proposed to take the cylinder for a model of a horizontal steam engine; to show it in several external elevations and an external plan, also in vertical cross, vertical longitudinal section, and sectional plan.

Actually, since each view of the cylinder will bear a direction relation with nearly every other view, the drawings should appear all in one sheet, so that centre lines and levels can be followed

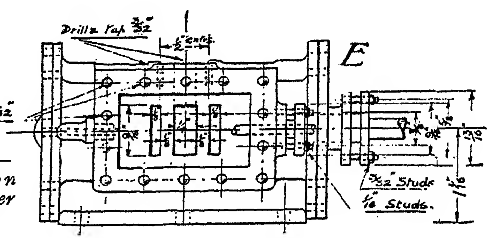


Fig. 68.—*Elevation with a cover removed.*

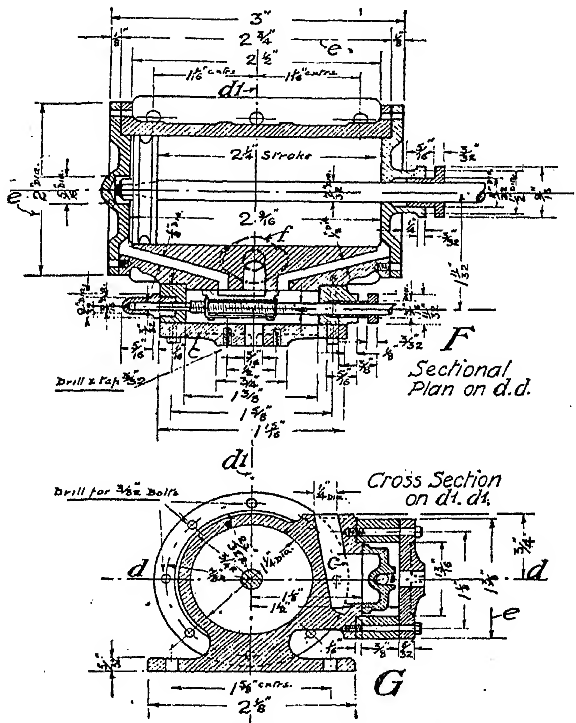
through; but the size of the page will preclude this, so we must be content with separate views.

Elevations.—Fig. 67 shows at A an outside elevation of the valve-chest side, at B a similar view of the opposite side, and at C and D the back cover and front cover ends respectively. The drawing B illustrates the use of the short-dotted line indicating the outline of the valve chest and ports. At E in Fig. 68 is an elevation of the valve chest with the cover removed in order to show the ports.

Sections.—So much for elevations. In Fig. 69 two sectional views of the cylinder are given: a horizontal section at F, i.e. a sectional plan on the longitudinal centre line *d* in view G, and a cross-section G taken through the cross-centre line marked *dl* in F.

In Figs. 68 and 69 the dotted and dash-dotted lines which are drawn bear letters corresponding to Fig. 67, and with references made at the commencement of this chapter.

Attention is called to the use of the line *f* in drawing F, Fig. 69. Here it will be seen that the dash-and-two-dot line indicates the facing for the exhaust-pipe flange. The line thus shows the position for this facing, notwithstanding that the upper half of the cylinder, of which the facing forms a part, is cut away.



9.—*Sectional plan and cross-section.*

Scales.—The greater majority of mechanical drawings are made to a scale reduction ; that is to say, they are not made—in most cases they cannot be—the full size of the required object. Such drawings made to scale bear a definite fractional relation to full size.

Such fractional relationship depends largely upon the most con-

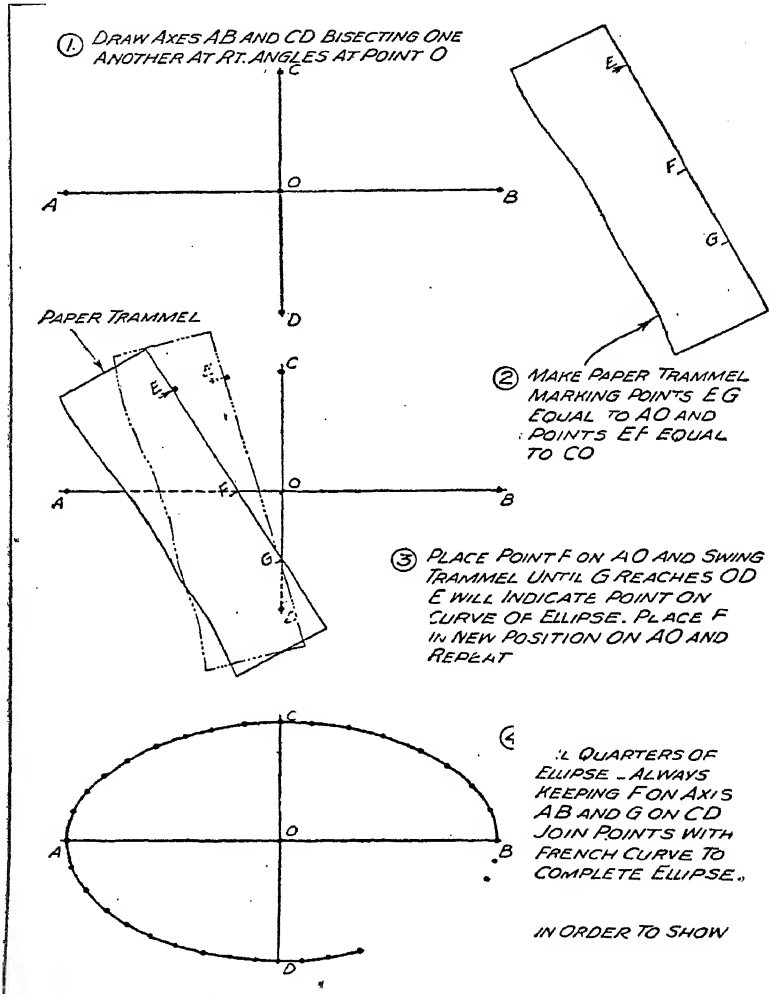


Fig. 70.—Various methods of drawing ellipses.

venient size for handling the sheet of paper and the size of the object.

In the first case a scale as small as, say, one-ninety-sixth, i.e. $\frac{1}{8}$ in. to 1 ft., may be most convenient, and in the second case the scale may be as large as one-fourth or even one-half, that is to say, 3 in. to 1 ft. or 6 in. to 1 ft.

All drawings will have either a statement of the scale written upon them or an actual constricted scale. In either case, when examining such drawings, all we have to do is to consider the scale as a miniature reduction of a foot rule of considerable length, in which only the first foot is divided into inches.

In order to take off a measurement of a part of the object, a pair of dividers is laid first over the part to be measured, and then, without altering the distance between the points, upon the scale in such a way that one point falls within the first inch-divided foot and the other upon the nearest figured foot, out along the scale. The number of feet, beyond zero, is read off, and added to this the number of inches on which the divider point is resting.

Sizes of Drawing Boards

Quarter Imperial	16 in. × 12 in.
Half Imperial .	23 in. × 16 in.
Imperial . .	31 in. × 23 in.
Double Elephant	42 in. × 29 in.
Antiquarian	54 in. × 33 in.
Extra Large ..	5 ft. 10 in. × 3 ft., 5 ft. 10 in. × 4 ft. 2 in., and 8 ft. 4 in. × 2 ft. 7 in.

Standard Sizes of Drawing Paper

Foolscap	17 in. × $13\frac{1}{2}$ in.
Demy	20 in. × $15\frac{1}{2}$ in
Medium	22 in. × $17\frac{1}{2}$ in
Royal	24 in. × 19 in
Super Royal	27 in. × 19 in
Elephant	28 in. × 23 in
Imperial	$30\frac{1}{2}$ in. × $23\frac{1}{2}$ in
Columbier	$34\frac{1}{2}$ in. × $23\frac{1}{2}$ in
Atlas	34 in. × 26 in
Double Elephant	40 in. × 27 in
Grand Eagle	$42\frac{3}{4}$ in. × 28 in
Antiquarian	53 in. × 51 in
Emperor	72 in. × 48 in
Double Emperor	96 in. × 69 in

BLUEPRINTS

The blueprint process is extensively used for making copies of engineers' tracings, and it can be used successfully for prints from photographic negatives if the negatives are strong and contrasting, having dense high lights and dense shadows. Weak, thin negatives—although giving good results with gaslight paper—are useless for making blueprints. The process is simple, cheap, and easy to work, for after exposure the prints only need a wash in water to make them permanent, thus avoiding the usual developing, toning, and fixing. This paper is very suitable for printing rough proofs, being much cheaper than self-toning or bromide papers. Up to certain limiting or practical dimensions, shop drawings are made full-size and especially so if the form and details of the item are so complicated that full and complete figuring is rendered impossible. In such a case, a true-to-scale print is issued and the mechanic is then able to measure up, straight off the drawing, for himself. As is well known, ordinary blueprints and black-line ferro-gallic prints shrink in the process of washing and drying; this renders them unfit for taking off unfigured dimensions. When, however, full figuring of measurements is possible in the drawing, such prints are sufficient for the shops to work from.

In the case of prints which go to the smiths and to the pattern-makers, coloured lines are added to the prints, or are otherwise indicated on the tracing, to show the surfaces which have to be machined, and on those surfaces, on the forgings and patterns, a surplus margin of material will be added, or allowed, to provide for such machining. For objects which are to have no rough or cast surfaces left, the words "machine all over" would be written on the drawing.

The Method of Printing.—This is carried out in the ordinary way, and should be continued until the deepest shadows assume a bronzed appearance. No time for printing can be given, as so much depends upon the light and the negative. A very few minutes would suffice in summer sunshine, but it might take a day or more in winter.

To finish the print, it is just washed in water after being removed from the printing frame until the water runs off clear and free from yellow tinge. The colour becomes darker as the print dries, and will be slightly improved if the wet print is subjected to a bath of extremely weak acid—say, a teaspoonful of vinegar in a pint of water —before the final rinsing in clean water.

Titles may be written on the finished print with an ordinary pen by using a solution of ordinary washing soda in place of ink. If the "print" is a tracing from a drawing, corrections or additions can be made in the same way.

Most drawing offices now use special machines for taking blue-prints from tracings.

Approximate Weight of 1 Cubic Inch of Metals

	Lb.		*Lb.*
Platinum	·78	Nickel	·31
Gold	·69	Wrought Iron	·28
Mercury	·49	Steel	·28
Lead	·41	Cast Iron	·26
Silver	·36	Tin	·26
Bismuth	·35	Zinc	·26
Copper	·32	Antimony	·24
Brass	·31	Aluminium	·097

Shrinkage of Castings

The allowance for shrinkage in castings should be (for each foot in length):

	Parts of an Inch.
For Cast-iron Pipes	$\cdot125 = \frac{1}{8}$
For Cast-iron Beams and Girders	$\cdot1 = \frac{1}{10}$
For Cast-iron Cylinders, Large	$\cdot094 = \frac{3}{32}$
For Cast-iron Cylinders, Small	$\cdot06 = \frac{1}{16}$
In Thick Breadth	$\cdot156 = \frac{5}{32}$
In Thin Breadth	$\cdot156 = \frac{5}{32}$
Brass	$\cdot17 = \frac{3}{16}$
Lead	$\cdot31 = \frac{5}{16}$
Zinc	$\cdot25 = \frac{1}{4}$
Copper	$\cdot17 = \frac{3}{16}$
Tin	$\cdot25 = \frac{1}{4}$
Bismuth	$\cdot156 = \frac{5}{32}$

READING AND USING THE MICROMETER AND VERNIER

The most common type of micrometer is that used for external measurements. Such a micrometer is seen in use in Fig. 72, where the diameter of a pin is being taken. This actual tool is what is known as a 1-in. micrometer, and it will deal with measurements in decimals of an inch from zero up to an inch. Briefly, it consists of the following parts: a flat, bow-shaped, stiff frame, into the inside of which at the top is fitted a hardened gauging face. Exactly opposite to this face and on the outside of the bow is arranged a stout machined tube. The tube is tapped inside with a thread, into which fits a threaded spindle

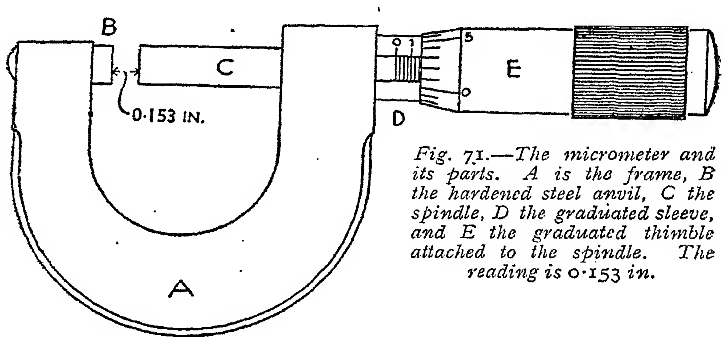


Fig. 71.—The micrometer and its parts. A is the frame, B the hardened steel anvil, C the spindle, D the graduated sleeve, and E the graduated thimble attached to the spindle. The reading is 0·153 in.

faced and hardened on the inner end to form an adjustable gauge face. Attached to the outer end of the spindle is a tube that is large enough in the bore to slide over the outside of the tapped tube. Thus, by turning the outer tube, the end of the screw will advance or recede in relation to the fixed gauging face. It is quite obvious, therefore, that, providing the pitch of the screw is accurate, if the gauging faces are in contact and the spindle is then unscrewed for one complete turn, the distance between the gauging faces will be exactly equal to the pitch of the thread. In order that the turns of the screw need not be counted, a line is engraved along the outside of the tapped tube, this being subdivided by short vertical lines spaced equal to the pitch of the thread. The edge of the outer tube is chamfered and engraved

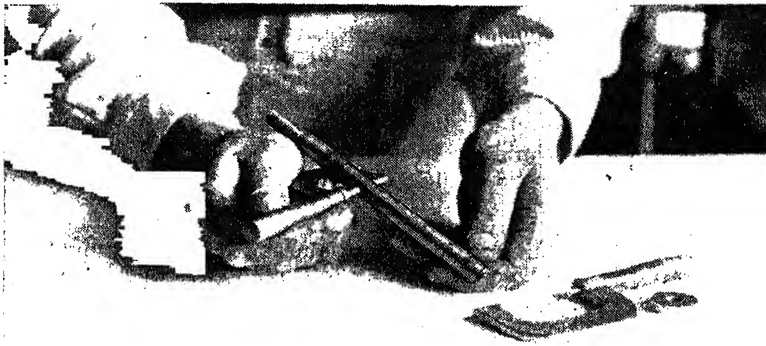


Fig. 72.—The line along the barrel of a micrometer is engraved so that when it is held as shown it is in the direct vision of the operator.

with equally spaced lines, so that the thread can be moved by complete turns or exact parts of a turn.

The fixed gauging face is called the anvil, the movable gauge face the spindle, while the tapped tube is known as the barrel and the outer tube the thimble.

Reading a Micrometer.—On a micrometer reading in inches the spindle is threaded 40 threads per inch. The line along the barrel is engraved, so that when the micrometer is held as shown in Fig. 72, it is in the direct vision of the operator. This line is, along its lower edge, divided into forty parts, every fourth line commencing from the frame being marked with a numeral from 1 to 10. The end of the thimble is graduated into twenty-five equal parts. When the gauging faces are touching, one of these lines exactly coincides with the long line on the barrel, and the feather edge of the thimble is in line with the first vertical line. This line on the thimble is marked 0, and every fifth line is marked with a number, thus, 5, 10, 15, 20. This means that the divisions along the barrel represent fortieths of an inch, and the distance between the numbered lines four fortieths, or $\frac{1}{10}$ in. The divisions on the thimble, then, represent one-twenty-fifth of one-fortieth, or $\frac{1}{1000}$ in. It will be seen that the reading is in decimal fractions. Thus $\frac{1}{2}$ in. becomes 0·5 in., and to set the micrometer to this size, the thimble is unscrewed until the zero mark on it corresponds to the line marked 5 on the barrel,

that is $\frac{5}{10}$ in. To give another example of setting, we will take the decimal equivalent of $\frac{3}{16}$ in., which is 0·1875 in., or one tenth, eight hundredths, and seven and a half thousandths. Set the zero mark on the thimble to number 1 on the barrel; three further complete turns to the spindle adds seventy-five thousandths; this leaves twelve and a half thousandths, or twelve and a half divisions on the thimble to be added.

Some 1-in. micrometers have the decimal equivalent of from $\frac{1}{64}$ in. to $\frac{63}{64}$ in. in sixty-fourths engraved on the frame, which is a very convenient arrangement.

Micrometers reading in tenths of thousandths are obtainable. These are read in the ordinary way to three places of decimals, but the fourth place is read on a vernier. Above the datum line on the barrel is another line parallel to it. This line corresponds to the fifth line on the thimble, with the zero mark set at the datum line. At a distance away from the second line equal to nine divisions on the thimble is another line, the space between these lines being divided into ten equal parts. The number of tenths of thousandths are added as follows: assume it is necessary to add 4; take the line marked 4 on the vernier and bring the line on the thimble that is nearest, alongside, keeping the thimble moving in a direction to unscrew the spindle.

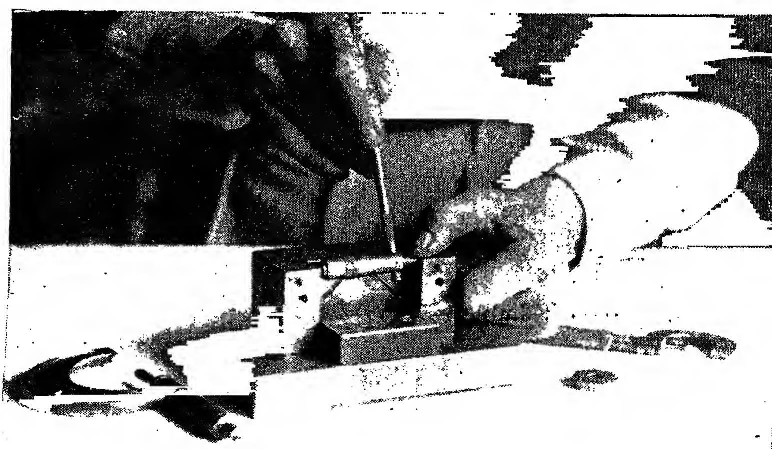


Fig. 73.—An inside micrometer in use. The micrometer shown in the bottom left-hand corner has a ratchet stop fitted.

Fig. 74.—To ensure that the lines of the vernier calliper coincide when adjusting it for a job, view them through a magnifying glass as shown.

Holding a Micrometer.—Reference to Fig. 72 again will show the correct way to hold a small micrometer; as will be seen, the frame lies in the palm of the hand with the thimble between the thumb and finger. This leaves the other hand free to manipulate the work being measured. In using the micrometer, a certain amount of "feel" must be cultivated, the thimble being adjusted so that the gauging faces are only lightly contacting with the surface of the work. Some thimbles are fitted with a device, namely, a ratchet stop, to ensure that the spindle is adjusted on to the work each time with the same degree of pressure. This arrangement is fitted on to the end of the thimble with a screw, upon which it is free to rotate. It is prevented from doing so by a spring-loaded pawl in the end of the thimble engaging in ratchet teeth cut in the end of the stop. The final adjustment is made to the spindle by turning the knurled portion of the ratchet stop; as soon as the end of the spindle is in contact with the work hard enough to overcome the pressure of the pawl, the ratchet teeth which are cut in a direction to override the pawl do so. The micrometer in the bottom left-hand corner of Fig. 73 has a ratchet stop fitted. When it is necessary to set the micrometer to size for use as a gap gauge, a means of locking the spindle is provided. Usually this in the form of a locking ring on the frame at the point where the spindle emerges. The ring tightens on to a collet through which the spindle passes.

Adjusting.—In common with other things, micrometers are subject to wear. Compensation for wear on the gauging faces is provided by making either the anvil adjustable or by making the position of the datum line movable. This is accomplished by fitting a friction-tight sleeve over the barrel. On the sleeve is engraved the markings that are normally on the barrel. By means of a special spanner the sleeve is rotated slightly to bring the datum line against the zero line on the thimble, being done, of course, with the spindle shut against the anvil.

After a fair amount of use the threaded spindle may become so slack a fit in the nut that backlash is created. The end of the barrel which is reduced in diameter is taper threaded and split by saw cuts down to the shoulder, a circular nut fitting over the end of the thread. To take up the wear, unscrew the thimble past the end of the barrel to reveal the circular nut. A pin on the special " cee " spanner supplied with the micrometer fits into a hole drilled in the nut. As this nut is tightened on to the tapered thread, it closes in the end of the spindle nut. This should be done very gradually, in order to make sure that the screw will not bind. Wind it into the nut for the full distance of travel between each tentative movement of the adjuster.

Types.—Micrometers are manufactured in a range of sizes covering from 0 to 1 in., 1 to 2 in., and so on. Those larger than the first are supplied complete with a standard test piece to facilitate checking and adjustment. A 1–2-in. micrometer and 1-in. standard are seen in the right-hand corner of Fig. 72. Apart from these types, a range of 0–2 in. is covered by micro-

Fig. 75.—The vernier calliper in use.

meters having either a sliding anvil or an inch extension that can be clamped on to the anvil. Other types, not in common use, are those in which the head is carried on a member sliding on a beam like a vernier calliper.

For inside measurements, a special type of micrometer is required. Such a tool is illustrated in Fig. 73. It will immediately be seen that the range of sizes that can be covered is governed by the overall length of the micrometer when closed. This is seldom less than 2 in. A hardened gauging face is fitted to one end of the thimble and a removable face on the end of the barrel. The overall length of the gauge can be increased by adjustment of the thimble by ½ in. beyond this; the range can be increased by means of a combination of distance rods and sleeves fitting into the end opposite to the thimble. Other methods employ distance rods that are ringed with a groove at intervals of ½ in. which engage with a lip formed inside a collet-like holder. A similar tool using a distance rod of this kind is the micrometer depth gauge.

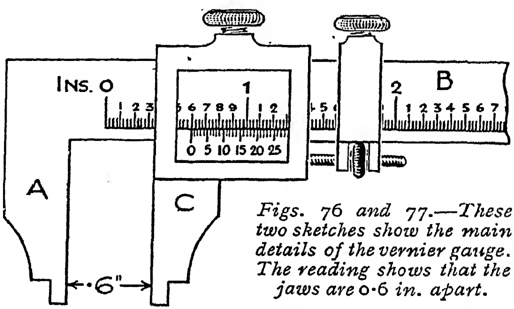
All types of micrometers are to be had in either English or metric readings. The pitch of the screw in a metric micrometer is ½ mm., the reading being $\frac{1}{100}$ mm.

The Vernier Calliper.—A vernier calliper, such as is shown in Fig. 74, will make measurements within the restriction of the graduated beam. These tools are chiefly used for measurements of length, as the largest diameter that can be covered is controlled by the depth of the jaws. As will be seen, the graduated bar carries a fixed gauging face on one end and a sliding face working along the beam. For English measurement the beam is graduated in the same way as the barrel of a micrometer, namely, in fortieths of an inch. In an opening cut in the sliding jaw is a plate which is also graduated. The total length occupied by these markings is equal to twenty-four fortieths on the beam, but the space between the lines is divided into twenty-five parts. Thus the vernier will read in one-thousandths of an inch.

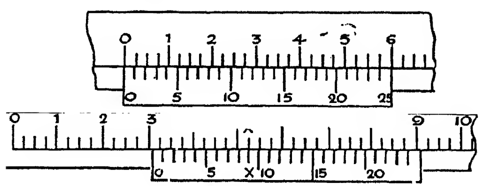
To make for easy setting, the beam is numbered off in inches, and every fourth fortieth in each inch is marked from 1 to 9 as a micrometer.

To set the gauge to, say, 4·619 in., the sliding head is moved along the beam until the zero mark on the scale passes the fourth inch marking; now it is taken to the sixth tenth of an inch marking past the 4 in., the reading now being 4·6 in. The locking screw on the fine adjustment, that is, the screw at the top of the part by the operator's right hand, is tightened and the jaws opened to the required extra nineteen thousandths by means

of the fine adjustment under the operator's thumb. To add the 0·019 in., bring the line at the end of the nineteenths division on the scale in line with the next fortieth line on the beam. To ensure that these lines coincide exactly, they are viewed through a magnifying glass as in Fig. 74. The vernier is shown in use in Fig. 75. It will be noticed that the lower end of the jaws are stepped. This is for the purpose of making inside measurements, such as the diameter of a hole. In reading, or setting for, such measurements, the total width over the stepped portions of the



Figs. 76 and 77.—These two sketches show the main details of the vernier gauge. The reading shows that the jaws are 0·6 *in. apart.*



jaws must be allowed for. So that if the vernier reads 2·110 in. and the width of the stepped portion is 0·300 in., the size of the hole is 2·110 + 0·300 in., or 2·410 in.; but to set to a certain size, the width of the jaws is subtracted first; thus, to set for an internal size of 3·750 in., the reading should be 3·450 in. On some verniers the beam is graduated on the reverse side, and a separate scale is marked with datum lines for inside and outside settings, the fine adjustment being carried out as before. Vernier callipers are also to be had which read in English on one side and metric on the reverse side.

Other classes of measuring tools are made incorporating the vernier principle. Notably these are depth gauges, height gauges, for marking out as with a scribing block, and gear-tooth

verniers. The depth gauges need no comment. Height gauges are similar to the vernier described, excepting that the fixed jaw is attached to a machined block that holds the beam in a vertical position in relation to the surface plate. Attached to the sliding

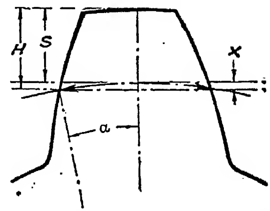


Fig. 78.—In measuring the thickness of gear teeth, it is necessary to add the chordal height x *to the addendum S. The vernier is set to height H. The height* $x = R(1 - \cos \alpha)$, *where* R = *pitch radius. Angle* $\alpha = 90° \div N$, *where* N = *number of teeth in the gear. Chordal thickness* = $2R \sin \alpha$, *or pitch dia.* × $\sin \alpha$, *where* $\alpha = \frac{1}{2}$ *angle subtended from the centre of the gear.*

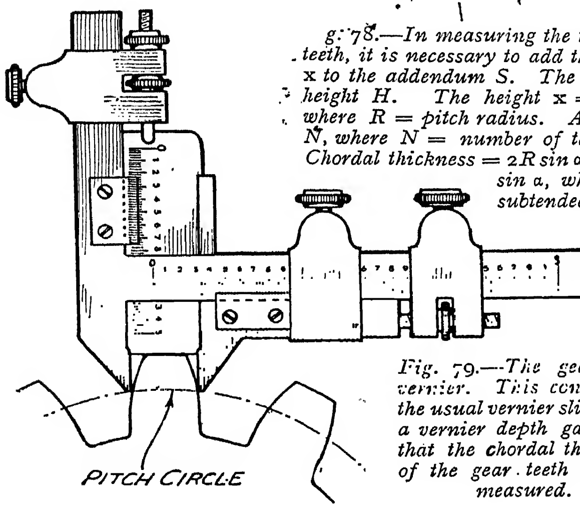


Fig. 79.—The gear-tooth vernier. This consists of the usual vernier slide plus a vernier depth gauge, so that the chordal thickness of the gear teeth can be measured.

jaw is a scriber of special design, enabling the measurement to which the tool is set being transferred in the form of a line to the work.

Gear-tooth verniers are a combination of two slides working at right angles, both reading off independent scales. On the one which has jaws like a vernier calliper is set the required thickness of the tooth at the pitch line. On the other, which is a depth gauge, is set the addendum, or the distance of the pitch line from the outside of the gear.

DRILLS AND DRILLING

Twist drills when properly ground and applied have many advantages over those of other types, and therefore are found in common use for work of a general character. In operation their chief characteristics are rapid cutting and self-clearing, and as this form of drill is also self guiding, a deep hole can, providing that the drill is rotated and fed in a fixed line, be drilled with reasonable assurance that the resultant hole will be straight throughout its depth. Further than this, the fact that resharpening may be carried out until almost the whole of the fluted portion of the drill has been utilised makes them most economical in use.

In order that the information may be rendered reasonably complete, and that relevant to the operation of regrinding made readily understandable, a brief survey of the different forms and sizes manufactured, together with the leading features of the design of twist drills in general, will be dealt with first.

Sizes and Types.—Most of the drills of the type mentioned can be had in two varieties, carbon and high-speed. This refers, of course, to the material from which the drills are made; but it would be as well to mention at once that those made from high-speed steel cost approximately twice as much as the others, and unless means are at hand to make full use of the special properties of the more expensive kind, no real benefit will result from their use. In fact, with the drilling speeds usually available in small workshops, carbon drills will give better service, inasmuch as the breakage of smaller drills will be a far less frequent occurrence.

The type of twist drill commonly stocked by the local tool shops is known as "jobber's" straight shank. The first word serves as a reference to the standard lengths to which the drills are made, and the shanks are equal in diameter to the nominal size of the drill. Such drills run up to $\frac{1}{2}$ in. or equivalent diameter, and are made from $\frac{1}{32}$ in. or smaller, advancing by $\frac{1}{64}$ in. upwards. An idea of the range of sizes covered may be gathered from the fact that it also covers metric, letter-gauge, and wire-gauge sizes.

Parallel Shank Drills.—For sizes above $\frac{1}{2}$ in. diameter to be used in a hand drill, or drilling machine having a chuck up to $\frac{1}{2}$-in. diameter capacity, there is a range of parallel shank drills, and although it is not suggested that they can all be driven in the manner mentioned, they run up to $1\frac{1}{2}$ in. diameter. Some of the heavier forms of hand-drilling machines have, in place of the usual chuck or taper socket, a simple form of chuck which will hold one only, namely, $\frac{1}{2}$ in. or $\frac{5}{8}$ in. diameter. The drive is

effected by means of a setscrew; hence the flat which is milled along the shank of this particular type of drill.

Drills from $\frac{3}{16}$ in. diameter upward are also made with Morse taper shanks. The particular number of the taper is governed by the most economical size of steel that can be used, having in mind also the diameter of the drill.

In total length these drills conform to the same standard as those known as "long series" straight-shank drills, and where an extra long drill is required, these are worth remembering. A comparison as to their length may be gauged from the fact that, whereas the overall length of a $\frac{1}{4}$-in. "jobber's" drill is 4 in., that of the same size in the "long series" is $6\frac{1}{8}$ in.

Apart from these types, there are those made with square shanks to suit ratchet braces, and also in the same shape for a carpenter's type of brace.

Any of the drills mentioned may be purchased singly or in sets.

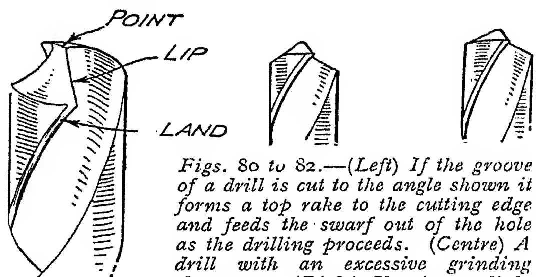
Points Regarding Design.—The usual form of twist drill has two flutes. These flutes are helically milled on opposite sides of the drill blank, the lead angle being approximately equal to the drill diameter multiplied by six. The flutes or grooves are milled with a special-shaped cutter, which generates a flat surface on the side that is to form the cutting edge, and the "hand" of the spiral is such that the positive rake is formed in relation to the cutting edge; this will be made clear by reference to Fig. 80. As the groove is cut at this angle, it forms top rake to the cutting edge, and feeds the swarf upwards out of the hole as the drilling proceeds. So that the sides of the drill do not bind when drilling, the drill is very slightly back tapered and also relieved until only a narrow "land" along the leading edges of each flute is left. The web left between the grooves forms the point of the drill, and the lips or cutting edges, for most purposes, fall away on each side to an included angle of approximately 120°.

The Cutting Action of the Drill.—For any cutting action to take place, it is only natural that the cutting edge or lip must be higher than the part of the drill immediately in the rear. It is probably the grinding of this clearance that represents the greatest difficulty to those not thoroughly acquainted with the requirements. The angle at which the clearance is ground governs the rate of feed. Thus a definite clearance of 1° would permit little more than a scraping cut being taken and requiring considerable pressure to make even that possible. On the other hand, excessive clearance is definitely bad, as it weakens the drill point and causes the cutting edges to wear rapidly. For the general run of work 10° of clearance at the edge of the drill will

be about right, the angle being made relative to the surface of the work. The clearance must increase towards the centre of the drill, and if the angle formed by the cutting edges and the line of the " point " connecting them are about 130° when looking at the drill end on, it may be taken for granted that such is the case.

Although the clearance angle given will be suitable for most purposes, it may to advantage be varied to suit widely different materials, and as a guide it can be remembered that the harder or tougher the material, the less is the clearance required.

Drill Grinding.—Resharpening or grinding becomes necessary after the cutting edges have become dulled by wear or through breakage. After a drill has been in use for some time, it may be that even after grinding the cutting edges, the tool will not cut freely and tends to bind in the hole. Where this trouble is experienced, examination will show that the lands have worn down



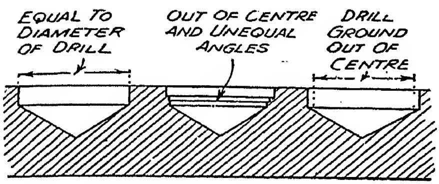
Figs. 80 to 82.—(Left) If the groove of a drill is cut to the angle shown it forms a top rake to the cutting edge and feeds the swarf out of the hole as the drilling proceeds. (Centre) A drill with an excessive grinding clearance. (Right) Showing a slight hump left in front of the cutting edge.

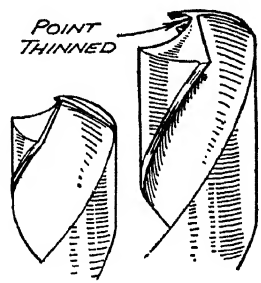
on the front, so making a short part of the drill undersize in diameter. The binding or squeaking is caused by the larger portion of the lands following being made to force their way into an undersize hole. Unless the drill is corrected at once, the whole of the land will wear off, or perhaps cause the drill to seize and break off in the hole. To put the matter right, the drill must first be ground back to remove the bad part. Bearing in mind what has already been said regarding clearance, the most important factor in accurate drilling is to grind the drill so that it will cut a hole of the intended diameter. To do this, it means that the point of the drill must be central, and also the slopes forming the cutting edges have to lie at equal angles with the axis of the drill. The special rests fitted to some small grinders are intended to facilitate this operation, and while such a rest certainly does serve to keep the drill steady, particularly where

the grinder is hand operated and used single handed, it must not be regarded in the same light as a proper twist-drill grinding attachment.

Regrinding a Drill.—It is a comparatively simple matter to " touch up " a drill that has lost its edge, as the original existing surfaces can easily be followed ; but where the grinding follows cutting back or breakage, it is suggested that it be done in the following manner, at all events until one is thoroughly accustomed to drill grinding.

After having ground off the end of the drill flat, proceed to





Figs. 83 to 85.—(Above). For important work the drill should be tried out on an odd piece of scrap material. (Right) A drill suitable for drilling brass. (Extreme right) If the point is too thick it retards the piercing action of the drill, and can be thinned to advantage by grinding as shown.

grind the slope on both sides of the point. Aim at getting both angles equal, the included angle correct, and both slopes the same length. Do this by presenting the drill straight on to the wheel at the required angle, ignoring for the moment the question of clearance. When satisfied that the grinding is as near as possible to requirements, grind the clearance by starting away from the cutting edge and grinding towards it, slightly rolling the drill backwards and forwards in the fingers while so doing. In this way the clearance can be brought up to the lips already ground without interference with the angle.

Faults in Grinding.—Common faults in grinding clearance are shown in Fig. 81, which is excessive, and Fig. 82, where there is a slight hump left in front of the cutting edge. For important work, the drill can be tried out in an odd piece of plate ; the first part of the section in Fig. 83 shows what should result from a correctly ground drill, and the second from a drill ground out of centre and with the slope angles unequal. Providing that the hole is not drilled too deep, it is quite easy, by placing the drill in the hole again after it is removed from the machine, to

see which slope requires correction. Where the drill is merely ground out of centre, it will produce an oversize hole, as in the third position, and here again it will be quite easy to see where the trouble lies.

The web between the flutes of a drill often increases in thickness towards the shank, so that as the drill becomes shorter the point is correspondingly wider. If the point is too thick, it retards the piercing action of the drill, and can be thinned to advantage by grinding as in Fig. 85.

For drilling metals such as brass, where the tendency is for the drill to feed too fast or "dig in," the rake of the lips may be reduced advantageously by grinding small flats on the front in an almost vertical plane, as in Fig. 84.

Other Drills.—The type of drill seen in Fig. 86 is intended purely for centring purposes, and is known as a "combination centre drill." In size, they run from "A" to "S" and from No. 1 to 10. Size "A" has a body $\frac{3}{16}$ in. diameter $\times$ $\frac{3}{32}$ in. and $\frac{1}{8}$-in. diameter points, "S" being $\frac{1}{8}$ in. diameter $\times$ No. 57 points. The number sizes run from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. diameter on the body. The speed at which centre drills should be run coincides with that suitable for a drill of a diameter similar to the point. Straight flute drills of the type shown in Fig. 87 are useful for brass and aluminium work, and are ground in the same manner as a twist drill. A set of such drills is usually included with a small "American" wheel brace, or can be bought separately, although not a generally stocked line.

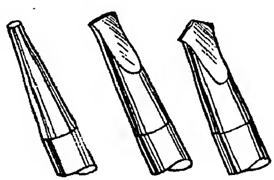


Fig. 88.—Three stages in making a drill.

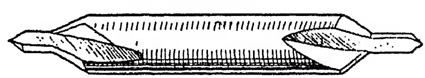


Fig. 86.—A drill intended purely for centring purposes.

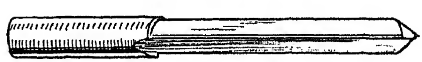
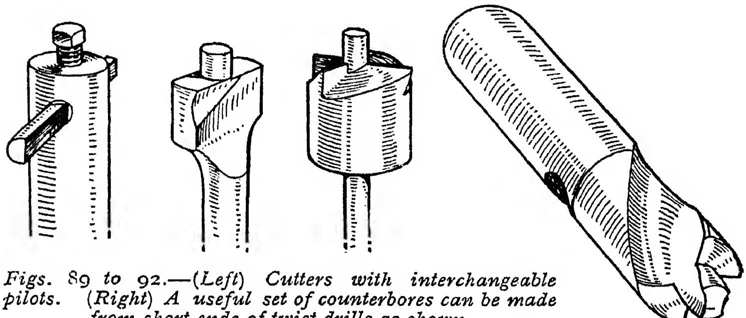


Fig. 87.—A straight flute drill.

Harpoon or flat-type drills are extremely easy to make where a special size is required. Large drills are forged from round bars smaller than the finished size required, the point and sides being turned true and to size before hardening. Small drills, however, must from a need for strength be made from larger silver-steel rod than the actual size of the drill. Fig. 88 shows the

three stages in making a small drill. A piece of rod is first tapered down to about half the diameter of the finished drill, and the end is then flattened out to give sufficient width. After hardening and tempering, the point is ground on to run true with the shank and the sides, and is afterwards ground to correct

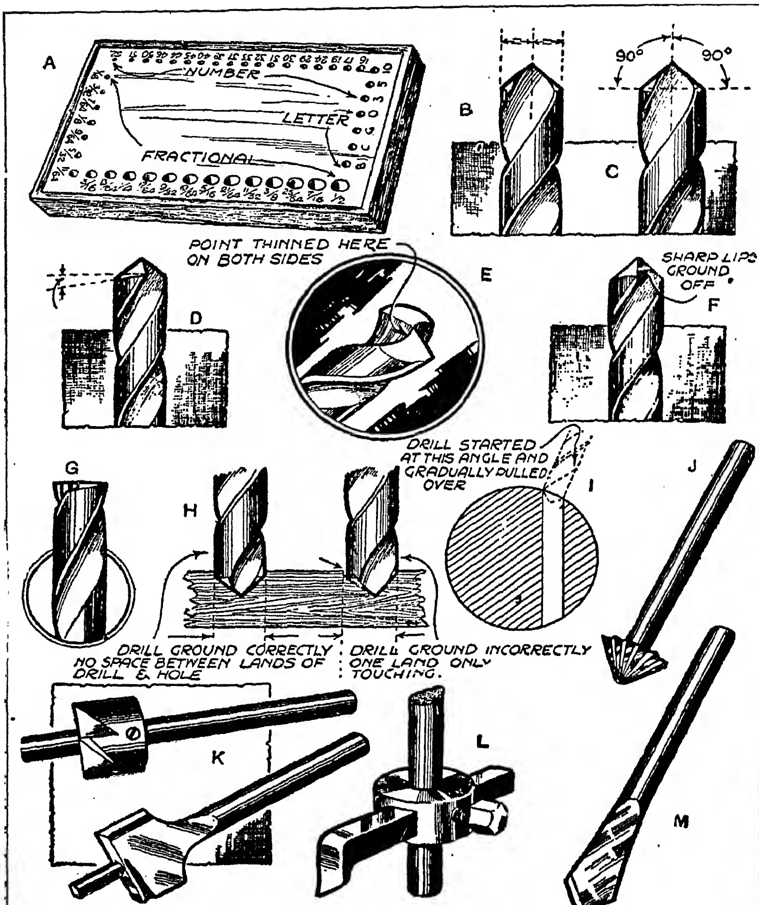


Figs. 89 to 92.—(Left) Cutters with interchangeable pilots. (Right) A useful set of counterbores can be made from short ends of twist drills as shown.

diameter. After cleaning up the flats by grinding, the point is "backed off." For tiny drills, stoning may be substituted for the grinding operations.

Counterbores.—The simplest method of counterboring small holes is to open out the mouth of the hole with a larger drill, finishing with the same drill ground to cut a flat bottom. This cannot be done unless the depth of the counterbore is fairly considerable, and for anything in the nature of spot facing or counterboring from an uneven surface, a pilot cutter is required.

There are many such types of cutters put up in sets with interchangeable pilots and cutters, or they may be made in any of the forms shown in Figs. 89 to 92. That in the centre is similar to a hollow mill, excepting that the bore is parallel and the cutter is pinned to a plain steel pilot and shank. For such a cutter to act as a deep counterbore, the sides of the teeth should be provided with relief. On the left is a plain cutter bar, which is suited to spot facing and counterboring larger diameters. The cutter is positioned and held by a pointed screw in the end of the bar, and resharpening is carried out by the removal of the cutter. The solid type of pin drill in the centre is another useful form, but in order to make it economically, a forging is required. When used for working steel, the cutting edges should be slightly lipped in the manner shown. Any of the types of cutters illustrated may be modified for radiusing or countersinking operations.



Figs. 93 to 104.—A, drill stand; B and C, the angles must be equal, the point central, and the backing-off equal; D and E, for drilling thick metal the point of the drill should be thinned; F, when drilling soft metals the sharp lip should be ground off; G, a finishing drill for flat-bottoming holes; H, drill ground correctly and incorrectly; I, drilling a hole in round material; J to M, various cutters.

A useful set of counterbores can be made from short ends of twist drills, as in Fig. 92. Unless means are available for cylindrically grinding the pilot, the job will have to be carried out on a lathe, in which case only the ends of carbon-steel drills should be used. After annealing, the pilot is turned a shade smaller than the size of the hole in which it is to work. Back off the cutting edges close up to the pilot before hardening and tempering. It is an advantage, where the pilot is sufficiently large in size, to undercut at the back to make the filing of the relief and subsequent sharpening easier. It is surprising how soon a useful range of such cutters is accumulated, if one is made as the occasion demands.

Speed of Drills.—A feed per revolution of ·004 in. to ·007 in. for $\frac{1}{4}$ in. and smaller, and from ·007 in. to ·015 in. for larger. This is computed on a surface speed of 30 ft. per minute for steel, 35 ft. per minute for iron, and 60 ft. per minute for brass.

MOTTLING AND FINISHING METAL SURFACES

For the mechanical method as employed on faceplates and machine tools, the articles are finished dead smooth first, then, with a tool similar to the ground-off end of a broken file (ground with a cutting edge), take off an infinitesimal portion of the surface of the plate or other article. The tool is held at an angle of about 35° to 40°, and the operator uses either a circular motion or an irregular backward-and-forward motion. The work is continued until the whole surface of the plate, etc., is beautifully mottled with wavy lines or patches as desired. A chemical method of producing a mottle of brown and green is to subject the thoroughly clean work to the action of a boiling solution of 8 oz. copper sulphate and 2 oz. sal-ammoniac in 1 gal. of water. When a brownish colour appears, transfer the work to a solution (cold) of 4 oz. salsoda in 1 gal. of water, floating on the surface of which second solution is some oil or petrol. On replacing the work in the first solution, a green colour appears; but, owing to the oil which spreads over the surface of the work, the actions of the two solutions are not even, and the colours become mixed.

SPECIAL CUTTERS

The particular cutters now referred to are non-standard, and therefore will require making to suit the job in hand. Reference to Fig. 105 will give an indication as to their sphere of application. From these shapes it will be gathered that, in order to produce the underhead profile, as it were, it is necessary to form a corresponding female shape on the face of the cutter.

As a general rule, parts finishing with a square corner, as at A, B, and C, can be stripped down, and the underhead profile formed in the operation. Where a fillet is required, as at D, it is better to strip the shank down with a standard hollow mill and then form the radius with a special one. This is necessary on account of the metal being cut tending to " crowd " into the mouth of the cutter where the corners are radiused. Therefore, an attempt to strip down the shank for any considerable distance

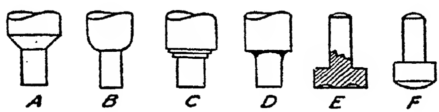


Fig. 105.—*Non-standard cutters that have to be made to suit the particular job in hand.*

with such a cutter would most likely result in seizure. Ending or head finishing, as shown at E and F, can also be carried out by means of this type of cutter.

The hollow cutters are gashed in the manner already described, but the backing off must follow the shape in the mouth of the cutter. It should be made clear that this method must not be employed for parts such as C, where the steps formed by the varying diameters adjacent to the shank are other than of a slight nature. These cutters require special treatment as regards backing off, and reference to Fig. 106 will make the matter clear.

Ending cutters require careful treatment in the matter of gashing, but here again, the necessary information can be better imparted by means of a sketch (see Fig. 107). When backing off such cutters, remember that it is easier to file the metal when soft than to use a stone after hardening. Therefore, bring the

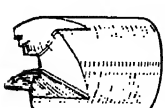
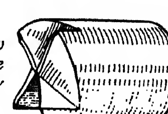


Fig. 106.—*Hollow cutters require special treatment as regards backing off, as will be seen from the sketch.*

Fig. 107.—*How ending cutters are treated in the matter of gashing.*



cutting edges up sharp with suitable fine files, and merely use a stone after hardening to impart a high degree of finish to the edges. Careful attention to this finish is an all-important point, if subsequent polishing of the product to remove toolmarks is to be avoided.

Taps.—Standard hand taps are readily obtainable in the general range of screw-thread systems in common use. Hand taps are put in sets of three, taper or starting, second, and finishing or bottoming. The products of different tap manufacturers may vary as regards the style in which the taps are made. This is an important point which is not perhaps generally realised, and is therefore worthy of mention, on account of the bearing that

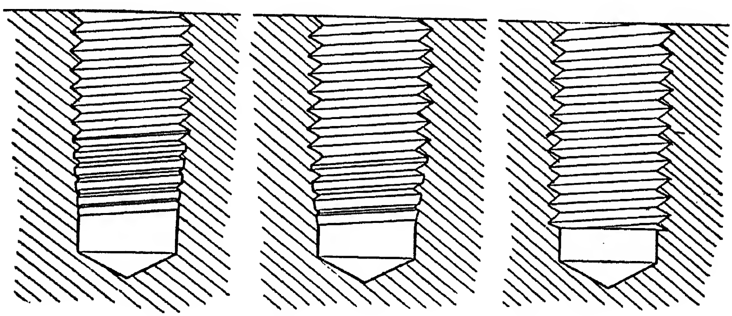


Fig. 108.—Three stages in tapping a blind hole.

it has on the tapping operation and also explains why size for size prices may vary.

The most familiar style is that in which the tap blanks are made identical as to diameter over the tops of the threads. The blank for the " taper " is reduced at the front to the core diameter of the thread, and a taper formed to wash out about half-way along the threaded portion. That for the " second " is treated in a similar manner, excepting that the taper is more abrupt, washing out in three or four threads, the " plug " blank being merely chamfered. After being fluted, the taps are relieved on the tapered portions away from the direction of rotation. Fig. 108 shows the three stages in tapping a blind hole with such taps. From this, it will be seen that the thread is completed from the root diameter outwards.

A Reversed Process.—Another style of tap is that in which the process is reversed. This is accomplished by making the taps

in each set with different outside diameters, the taper being the smallest and the bottoming tap only correct to size. The successive stages of tapping are shown in Fig. 109. Such taps are, in addition, an indication as to nominal diameter and threads per inch, clearly marked by one, two, or three annular rings on the shank to denote the correct order of usage. Backing off is achieved as previously mentioned. While this style of tap is undoubtedly superior for tapping deep holes in tough material, it is perhaps not so suitable for amateurs as that first mentioned, as an ordinary taper tap will produce at once a full thread in a clear hole in steel up to a thickness equal to about $1\frac{1}{2}$ times the diameter of the tap.

Certain makes of taper taps are made in the form shown in

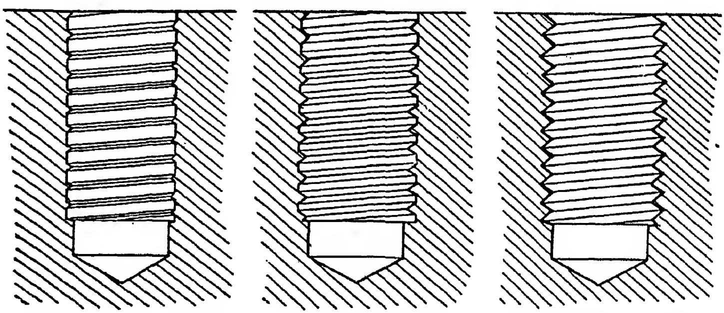


Fig. 109.—This style of tap is suitable for tapping deep holes in tough material.

Fig. 110. The diameter of the front portion is equal to the correct tapping size, and is unrelieved. It is obvious that the intention is to provide a pilot to maintain the axis of the tap in line with the drilled hole, and is a feature that saves considerable time in starting the tap square with the work.

The free-cutting properties of a tap are greatly enhanced by reducing the width of the land to a minimum. Unfortunately, such reduction, by increasing the width of the flutes, produces a weak tap. This objection may be overcome, to a certain extent, by relieving the taps of the threads, as shown in Fig. 111.

A satisfactory method of reducing the land without detracting from strength is to be found in the class of tap having relieved threads, that is, the threads are relieved at the root, crest, and flanks, as shown in Figs. 111 and 112. Such taps are naturally more costly than those of other types, and are not to be had in smaller sizes.

Using Taps.—More taps finish their career by breakage than by becoming " worn out." Thus it would appear that, in using taps, the main point to guard against is breakage. Most of the causes contributory to breakage are inconsistent with the practice necessary for the production of good tapped holes. Therefore, it follows that the avoidance of the causes of breakage enumerated will represent the correct method of usage in order to produce good work.

One of the most important points is to drill a tapping hole of the correct diameter, while in softer materials and also for finer-pitched threads it is necessary to have the tapping hole of such a size that a full thread will result. It is an advantage, where there is a deep thread of coarse pitch, such as any of the larger sizes (above $\frac{3}{16}$ in.) in the Standard Whitworth range, to drill the tapping hole oversize. The amount permissible will naturally

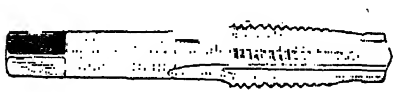
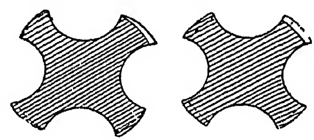


Fig. 110.—*Certain makes of taper tap are made in the form shown.*



Figs. 111 *and* 112.—(*Left*) *Overcoming a weak tap by relieving the taps of the thread and* (*right*) *a tap with the threads relieved at the root, crest, and flanks.*

be dictated by the particular requirements of the work, but as a general rule can be anything that will allow at least two-thirds of a full thread being tapped.

Breakage frequently results from the failure to start the tap square with the hole. Fig. 113 shows the bending strain imposed on the tap when entered out of square. The use of a tap wrench providing unequal leverage will also tend to produce a similar result. While on the subject of wrenches, it should be mentioned that the leverage used must not be sufficient to lose the " feel " of the tap cutting.

In tapping deep blind holes, chips can cause a lot of trouble, either by building up under the end of the tap, filling the flutes, or locking the tap. The latter condition is overcome by reversing the tap occasionally while feeding in. When tapping a blind hole in steel, a lot of work is left for the second and plug taps to do, unless the tapping hole can be drilled considerably deeper than the actual amount of thread required. Where this is not permissible, the thread is carried to depth by alternate use of the

second and plug taps. Where very shallow blind holes have to be tapped, the method shown in Fig. 114 will be found useful.

Avoid, if possible, carrying the thread in a blind hole down until the end of the plug tap strikes the bottom, as this may chip the end, thus making the removal of the tap a difficult matter.

Although certain materials tap satisfactorily dry, always use a suitable lubricant for deep holes in all cases, excepting for cast iron. This fact is most essential where steel is being employed. The use of blunt taps not only increases the physical effort required to drive the tap, but also increases the risk of breakage. Fig. 115 shows the section of dull tap, and it is usually sufficient to grind these rounded edges of the flutes to restore the tap to an efficient working condition (see Fig. 116).

Where it is necessary to regrind a taper or second tap on the

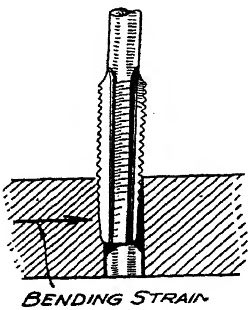


Fig. 113.—*Showing the bending strain imposed on the tap when entered out of square.*

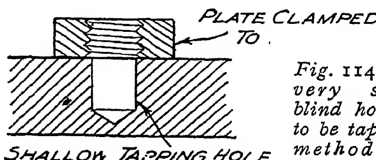


Fig. 114.—*Where very shallow blind holes have to be tapped, the method shown here will prove satisfactory.*

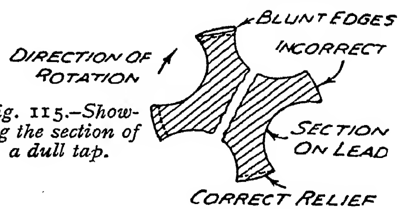


Fig. 115.—*Showing the section of a dull tap.*

tapered portion, see that the "backing off" is not overdone (as in Fig. 115), or the tap will merely act as a reamer or chatter badly.

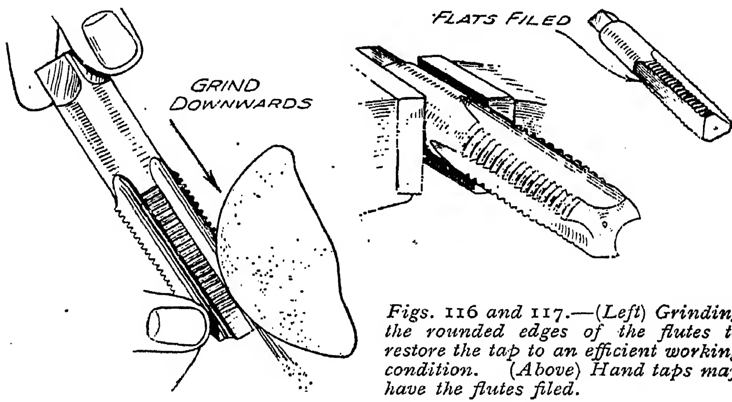
Taper Taps.—A type of tap that is extremely handy, where a number of small thin parts of a nut-like character have to be tapped, is what is known as a machine-shank tap. Such taps are intended for use in nut-tapping machines, and can be had in sizes down to No. 8 B.A.

The shanks of these taps are longer than those of the hand variety, the diameter being smaller than the core diameter of the thread. Such taps may be driven in a lathe or drilling machine, the work being continuously fed on to the tap and passed over on to the shank. As soon as the shank is full of

parts, the tap is removed from the machine and they are slid off. Ordinary hand taps may be converted by reducing the diameter of the shank.

Tap Making.—It is often only by means of a special tap that a satisfactory repair job can be carried out, as, for instance, when badly damaged threads in a part that cannot be mounted on the lathe have to be cleaned out, or when, for the purpose of a repair, a thread is required in an existing odd-sized hole.

Without going into details regarding the turning of the tap blank, it is sufficient to say that the thread is carefully cut and



Figs. 116 *and* 117.—(*Left*) *Grinding the rounded edges of the flutes to restore the tap to an efficient working condition.* (*Above*) *Hand taps may have the flutes filed.*

finished to correct form with a suitable chaser. The design of the blank will depend upon the purpose for which it is intended, and also upon the means available for cutting the flutes. If the tap is required merely to clean out a thread, then the threaded portion needs only to be made very short. As regards material, in many instances mild steel, if subsequently case hardened, is good enough. The first two or three threads are tapered down to the core diameter in the lathe. If the tap is a large one, the blank is turned with a reduced shank, and the flutes roughed out by slotting in the lathe and finished off by hand with a round file to remove the burrs thrown up in the threads, the leads being backed off with a fine file, as in Fig. 117.

Reverting to the question of cutting the flutes, it is, of course, presumed that means for milling them are not available.

With smaller taps that are made from silver-steel rod, without prior turning, the flutes may be filed in, as in Fig. 117. It will be noticed that the flutes wash out gradually towards the shank, and while this is not an ideal form, the tap will be quite satisfactory excepting for prolonged service. In filing the flutes, emphasis is laid on the fact that the edges must be finished cleanly. A good plan is to first file a groove with a three-square file down what will be the centre of the flute to act as a guide for the round file.

An easier way of "fluting" small blanks is seen in Fig. 117, but taps made in this manner are only suitable for brass and similar material.

Although silver steel is a suitable material for small tap making, larger ones for work of any consequence should be made from a "non-shrink" class of tool steel. This is mentioned, as a tap made from ordinary cast steel may shrink in hardening and cause serious pitch error.

Where a suitable wheel is available, the cutting edges of the flutes will be improved by grinding, but in any case they should be "stoned" together, with the relieved portion which does the actual cutting.

REAMERS

For the purpose of providing a seating for a certain type of screw head or for lightly chamfering the mouth of a hole under a drilling machine, some form of countersinking tool is necessary. Such operations require to be cleanly done, that is to say, free from "chatter marks" and scores. Where the countersink is to accommodate a screw head, it is essential that the angle be correct to enable the cone to seat properly. It is quite possible to produce good work with an ordinary twist drill modified by grinding the

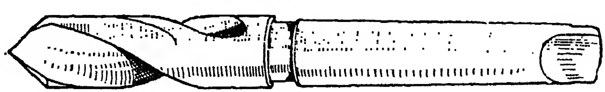


Fig. 118.—Best results will be produced when the clearance of the drill is cut to an absolute minimum.

point to a suitable angle. In fact, this method is preferable where the screw head is recessed below the surface. There is, however, one very important point to be observed in the matter of grinding the clearance if satisfactory results are to be obtained. As a general rule the appearance of a hole that has been countersunk by means of a twist drill looks anything but pleasing. This is chiefly

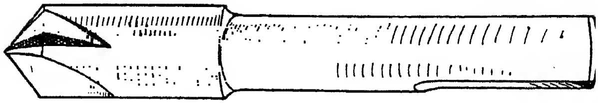


Fig. 119.—A special tool for countersinking.

due to the amount of clearance on the drill, and the best results will be produced when the clearance is cut down to the absolute minimum (see Fig. 118). Further advantages on the matter of finish will be gained if the ground part of the drill is "stoned" up.

Objections may be raised against modifying full-length drills and keeping them for use as countersinks, although for a special job the drill can be altered temporarily; but there is nothing to prevent short ends of drills being ground in this manner and kept for the special purpose.

There is, however, a special type of tool made for countersinking. This is made in various forms: the most common is that shown in Fig. 119. The teeth may vary in number, but the four-tooth variety gives good results in steel. Resharpening is carried out by stoning or grinding, but where the latter course is adopted, care must be taken to grind evenly, so that each cutting edge does an equal share of work. Precautions must also be taken to see that the clearance is not excessive, if "chattering" is to be avoided. Small rose countersinks do not lend themselves to resharpening except perhaps to a minor degree. In any case,

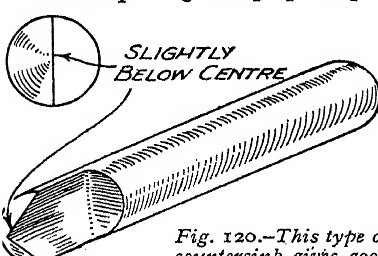


Fig. 120.—This type of countersink gives good results on soft brass.

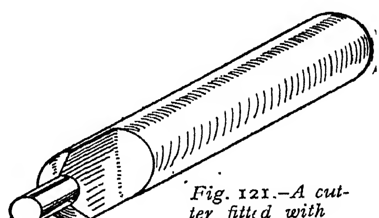


Fig. 121.—A cutter fitted with pilot.

they are only intended to be used on the softer materials, like brass and aluminium alloy.

Dee Bits.—The type of countersink shown in Fig. 120 gives good results on soft brass and aluminium, and produces a clean finish in what are really difficult mediums to machine. It can also be used for mild steel, gunmetal, hard brass, etc. An advan-

tage possessed by such cutters is that they are easily made from silver steel of a suitable diameter. The only machining necessary is to turn the point on the end ; the flat is filed slightly below the centre, and the tool hardened and tempered. How simple is the making of such cutters may be gathered from the illustration. Where the countersink must be true with the hole, it is advisable to make the cutter with a pilot (see Fig. 121), but where this is done the pilot is left solid, so as to prevent the hole from being reamed larger. It will be readily apparent that the sphere of usefulness of such cutters is not confined to countersinking operations, as by suitably shaping the blank a hole can be mouthed out to almost any shape. Incidentally, the small amount of trouble taken in making the cutter will reflect to advantage in the quality of the finished job. A group of special cutters is shown in Fig. 122. The first is suitable for forming a radius on the mouth of a hole, the second produces a special seating, the

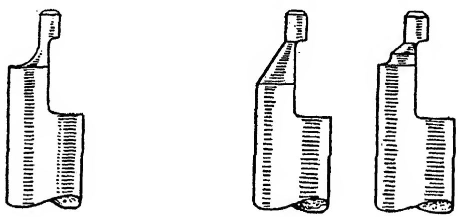


Fig. 122.—A group of special cutters.

third a special taper, and the last is a combination countersinking and radiusing cutter. Thus it will be seen that these cutters when made to suitable contours have a wide range of application. It must be mentioned, however, that this style of cutter will not be satisfactory if the contour includes a shoulder at right angles to the pilot, as when such a surface reaches the work, the cutting action ceases. This can often be turned to advantage where a number of countersinks or seatings have to be drilled to exactly the same depth, by providing a shoulder on the cutter to act as a stop. The cutters shown are provided with pilots, but this feature is only essential when the operation must be performed true with the hole. It should be pointed out that all cutters of this description cut on one edge ; and to restore when dulled, the flat surface only is stoned.

Reamers.—Before dealing with the various forms of toothed reamers, mention must be made of the fact that for certain classes

of work, more particularly of brass and gunmetal, special reamers may be made in the form of Dee bits. Such a reamer is shown in Fig. 123. A reamer of this description will, when properly made, produce a beautifully finished flat-bottomed hole in brass or gunmetal. It should be noted that for flat bottoming the end must be backed off at about 4° or 5° as shown, and the flat surfaces require to be perfectly finished after hardening. The end may, of course, be modified within certain limits to produce

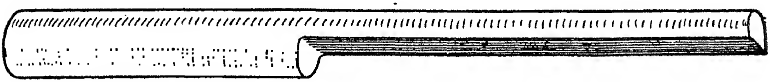


Fig. 123.—A reamer made in the form of a Dee bit.

a base of almost any shape; but where the end of the cutter must terminate in a point, the prior drilling operation must be carried out in such a manner that no appreciable amount of metal is removed by the extremity. Where the diameter of the hole is such that the correct-sized silver steel is not available, or a hole other than parallel is required, care must be taken to see, when reducing the blank to the requisite diameter or taper, that a high degree of finish is obtained. This is most essential.

Fluted Reamers.—Fluted reamers are made in many different styles, and the first to be considered are what are known as parallel hand reamers. These are to be had with straight or spiral teeth, as in Fig. 124. In order to facilitate the entry into a hole, the end of the toothed portion is tapered. This taper is usually of the order of about 1° a side, and extends to a distance equal to $1\frac{1}{2}$ times the diameter. While suited to reaming out bushings or like objects, where the reamer can pass right through the job, a bottoming reamer having no lead must be used to follow up where a blind hole has to be dealt with.

Most straight-toothed reamers have teeth unevenly spaced, the object of this being to prevent chattering. The teeth are

Fig. 124.—A fluted reamer.

relieved, but a narrow "land" is left along the parallel portion, and although the relief on the lead may be stoned up, any attempt at sharpening generally should be confined to stoning

the fronts of the teeth. Great care should be taken with the storage of reamers, as they will quickly become dull if allowed to rub together in a box. To secure the best results from a hand reamer, leave as little metal as possible for it to remove, and also feed it into the work at an even rate per revolution. This is not always an easy matter, and some hand reamers have a threaded lead, which pulls the reamer into the hole at a definite rate of feed, a feature offering a marked advantage in use on phosphor bronze.

Machine Reamers.—Reamers intended for machine use may differ from hand reamers only so far as the shank is concerned. There are, however, types which are widely different. Shell reamers may be regarded as the fluted portion of a short reamer. The lead is at an angle of approximately 45° on the front of the teeth. A hole through the centre of the reamer accommodates a separate shank, the drive being taken by a flat cotter. Rose-shell reamers differ only as regards the arrangement of the teeth.

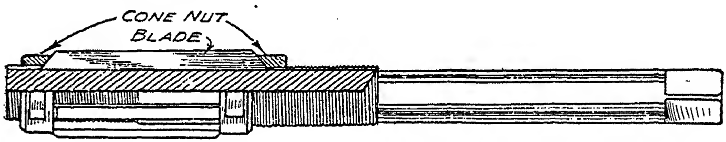
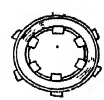


Fig. 125.—An adjustable reamer with both straight and helical blades.



In this instance, the cutting takes place on the front, the body being fluted to admit lubricant. The land between each flute is extremely wide, and therefore no cutting action can take place. The purpose of this class of reamer is to remove a lot of metal, such as enlarging a cored hole. Once the reamer has started truly, it must continue so on account of the guide afforded by the cylindrical portion. An ordinary reamer having narrow lands would tend to follow any irregularities in the cored hole.

Expanding Reamers.—The reamers so far dealt with are only capable of producing holes equal in diameter to the nominal size. A solid reamer that is sharp can be made to cut a few thousandths oversize by inserting a strip of foil between one of the teeth and the work. As the reamer is fed in, this has the effect of forcing the opposing teeth over to one side of the hole. This method cannot be relied upon with any degree of certainty, and the surest method is to use a reamer of correct diameter. Where the hole required happens to be an odd size, that is, not

to a fraction of $\frac{1}{64}$ in. or to an even millimètre, a special reamer will be required. This is quite a practical proposition where such a tool will be constantly required, but for occasional use an adjustable reamer will suit the purpose better.

There is one type of reamer of American origin which is similar in appearance to a solid reamer, with the exception that a short portion of the blank is left unfluted at the bottom. This short portion is a few thousandths smaller than the body of the reamer, and acts as a pilot. A hole is drilled up the body from the pilot, extending beyond the end of the flutes, and a counterbored hole terminates in a slow taper half-way up the flutes. Three equally-spaced narrow slots are cut at the roots of the teeth in the centre hole, the extent of the slots being confined to the toothed portion. The counterbored hole is tapped at the mouth, and the adjustment is effected by means of a screwed taper plug. It will thus be apparent that the slots are opened, causing the reamer to become slightly barrel shaped, and therefore, on account of the liability of the reamer to break if the screw is forced in too far, the range of adjustment is limited to a comparatively small amount. As recommended by the manufacturers, the following limits of expansion should not be exceeded: for reamers $\frac{1}{4}$–$\frac{9}{16}$ in. in diameter, plus 0·005 in.; $\frac{5}{8}$–$\frac{13}{16}$ in., plus ·008 in., and $\frac{7}{8}$–1 in., plus ·010 in.

Another similar type of reamer having a narrow range of adjustments is intended for machine use. In this the fluted portion is short, and is expanded by means of a cone bolt operating on the front end. The slots in this instance are carried out to the end, and therefore the greatest expansion takes place on the front end.

Inserted Blade Types.—Adjustable reamers of this type have a much greater range of adjustment. That shown in Fig. 125 is made with both straight and helical blades. Reference to the part-sectional view should make the construction clear, but briefly this is as follows: the body, made of good-quality alloy steel, is turned integral with the shank, and the screwed portions accommodate female coned nuts. Equally spaced slots are milled in the body to receive the blades, and the bottoms of these slots taper upwards towards the shank. The blades fit neatly into the slots, the ends being shaped to suit the conical faces in the nuts; incidentally, they are all exactly the same length. When the nuts are locked, the blades are forced on the bottom of the slots and held secure. When in the position shown in the sketch, the reamer blades are at their minimum diameter. By slackening the back nut and tightening the front one, the blades are forced upwards along the tapering slots, thus

causing the cutting edges to increase in diameter. The smallest sizes are provided with four blades and the others with six. Thus it is an easy matter to set the blades with the aid of a micrometer. As an indication of the range of sizes covered, it may be mentioned that 11 reamers cover all sizes from $\frac{3}{8}$ in. to $1\frac{1}{16}$ in. The total expansion on each of the three lesser sizes is $\frac{1}{32}$ in., but as the diameter increases, so does the amount of adjustment; the largest reamer mentioned expands from $\frac{15}{16}$ in. to $1\frac{1}{16}$ in. On account of the method of construction, the maximum size can be conveniently increased by inserting a strip of foil or tin underneath each blade. Spare blades are obtainable when required, these being supplied in sets of four or six as the case may be. One drawback to this particular pattern is that it is unsuitable for use in blind holes. This objection is overcome by the design of the "Vickers" adjustable reamer illustrated in Fig. 126. Here the blades slide outwards, and a micrometer adjustment is afforded by graduations on the head of the centre screw. Fig. 127 shows a longitudinal section; notice the shape

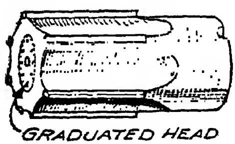
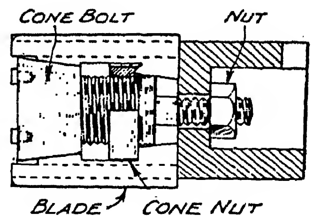


Fig. 126. — *A Vickers adjustable reamer.*

Fig. 127.—(*Right*) *A longitudinal section of the adjustable reamer shown in Fig.* 126.

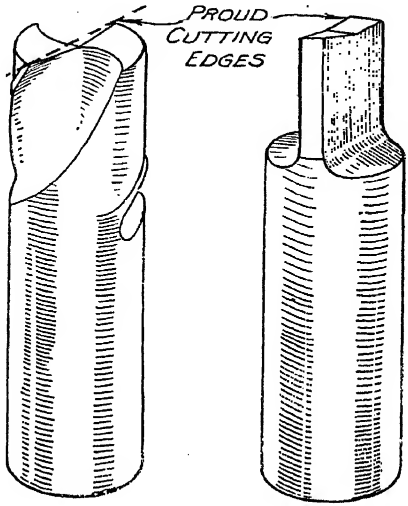


of the blades. The locknut is first released and the cone bolt screwed in by means of a special key to effect adjustment. The cone nut holds the blades in position, bearing being taken on both ends of the central cone; again the blades are renewable.

These reamers run from $\frac{5}{8}$ in. diameter upwards, this size being capable of expanding ·014 in. A separate shank is required as with shell reamers, the drive between being taken by a cotter.

Taper Reamers.—Solid taper reamers are available in Morse and Brown and Sharp tapers, as are also standard taper-pin reamers, having a standard taper of $\frac{1}{4}$ in. per foot, and arranged in a series so that a continuous taper is formed, with a margin for overlap by the set of reamers. Thus the large end of the reamer is greater in diameter than the small end of the next size in the series. Such reamers may be marked in fractions of an inch to correspond to the nominal diameter of the taper pin,

or 000, 00, 0, 1, 2, etc., from small to large. In use, taper-pin reamers require raising occasionally to break the chips in long holes. This prevents gapping the flutes.



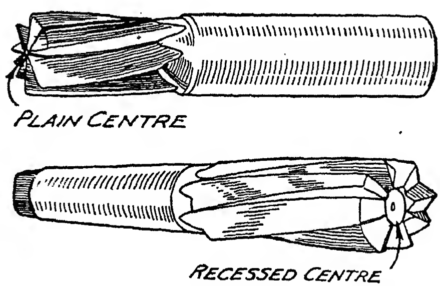
Figs. 128 and 129.—(Left) Adapting a broken twist drill for making keyways or slots; and (right) a simple type of cutter is the flat "fish-tail" shown, which can be made as occasion arises.

OTHER CUTTERS

Providing that certain precautions are taken, a broken twist drill can be utilised to mill very satisfactory keyways or slots. The first point is that the fluted part of the broken drill must be ground off extremely short, the relief being ground in a similar manner as for a flat-bottoming drill, but with the following exceptions: Instead of the normal cutting edges being in line at right angles to the axis, they are ground to form proud cutting edges adjacent to the lands, as seen in Fig. 128. This permits the centre to clear properly, and allows fairly heavy cuts to be taken. Other important points are that the cutter runs perfectly true and is rigidly held. For the latter reason, where small drills are so utilised, unless a collet is available for holding, they must

needs be sweated into a stiff mild-steel bar-holder, leaving little more than the fluted part projecting. Although fairly heavy cuts can be taken, in comparison with the diameter of the drill, of course, each cut has to be "worked" on if wobble is to be avoided, that is to say, each cut is put on gradually while the work is being traversed backwards and forwards for a short distance, and when sufficiently deep, carried to the full distance.

Cutter Wobble.—Where the cut is fed straight in, the tendency of the cutter to wobble, and as a consequence increase the width of the slot at one point, is caused by the resistance offered by the pip formed between the points of the cutter. As, for instance, if a $\frac{1}{32}$-in. cut can be taken, a conical piece of metal of this height has to be removed before the traversing cut can



Figs. 130 *and* 131.—*Showing two types of spiral cutter. That with the recessed centre will be found the more serviceable of the two.*

commence freely. In overcoming this obstacle, the cutter is either forced upwards or downwards according to the direction of traverse, and will more than likely result in breakage. These remarks, by the way, apply to all types of end-milling cutters when used for the purpose of producing work of the same character as blind-ended slots.

A Simple Type of Cutter.—A simple type of cutter and one that can easily be made as occasion arises is that shown in Fig. 129. This is a flat "fish-tail" cutter, and can be used for the same purpose as the cutter which was improvised from a drill, or for light surfacing operations. The cutter will probably do all that is required if made from silver-steel rod, and the actual making is quite a simple matter. After flatting off the sides to leave a short central tongue, the relief is filed on the front and sides.

It may be mentioned that no land is left at the sides, the relief being brought up to a sharp edge. Subsequent hardening and tempering will, of course, be necessary before using.

Fluted Cutters.—Fluted or toothed-end milling cutters are obtainable in both carbon and high-speed tool steels. As regards the style of the shank, they are made in both parallel or straight, and the usual standard machine tapers. Again, the teeth may be either straight or spiral cut. Figs. 130 and 131 show two types

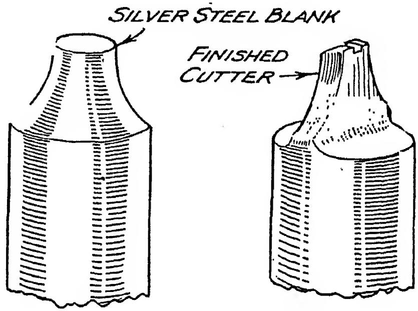


Fig. 132.—(Left) The blank from which is made the cutter on the right. It will be found useful for awkward jobs.

of spiral cutters. Of the two, that having the recessed centre is perhaps the most serviceable, at all events, as far as ease in resharpening is concerned. The benefit of the latter with spiral

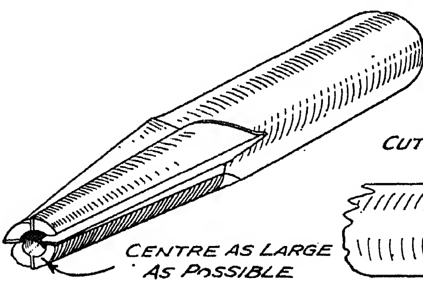
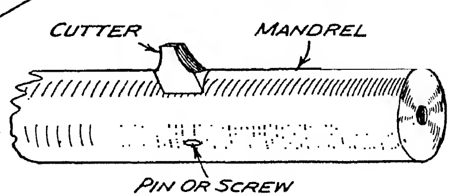


Fig. 133.—Slender cutters of special nature are best made in the toothed form shown.

Fig. 134.—An alternative cutter with reversible bit.



teeth will be noticed where the side of the cutter is used, as not only will less power be required for driving, but the thrust created is such that it tends to force the taper shank of the cutter hard into its socket. To make a satisfactory job of re-sharpening the end teeth, it is necessary that it be done in such a manner that each tooth will do an equal share of the cutting.

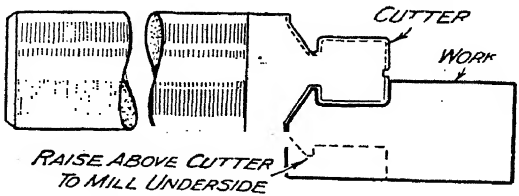


Fig. 135.—*Another type of flat cutter which will perform an endless number of jobs.*

The proper way to ensure this is by regrinding in a special fixture on a tool and cutting grinder, but if a stone is held against the face of the teeth while the cutter is run backwards, a land will be produced to serve as a guide for careful hand grinding to give a relief of from 5° to 7° to the teeth. It is not advisable to attempt to grind the sides of the teeth by hand, as this is essentially a machine operation. End mills with straight-cut teeth

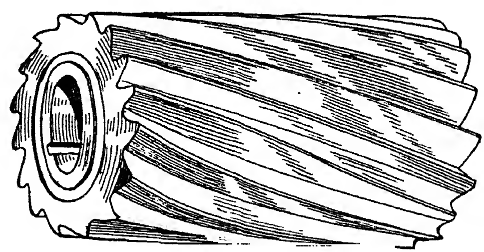


Fig. 136.—*This type of cutter is known as a roller or cylindrical cutter.*

may be touched up in a minor degree by stoning, it being remembered that no land is required. When using the side of an end mill, an important point to bear in mind is to feed the work against the direction in which the teeth are rotating. In fact, this rule applies to the use of all milling cutters.

Profiled End Mills.—Standard cutters may be slightly modified to produce slots with chamfered or radiused corners, by appropriately altering the corners of the teeth to achieve the desired result. On the other hand, by preparing a turned blank to the shape, as for example that shown in Fig. 132 left hand, and from it making a cutter in the form shown in Fig. 132 right hand, awkward jobs may be overcome. Notice that the centre of the cutter is slightly overlapped. This overlapping of the cutting edges is important where the end of the cutter is used to form a channel, as, if the slot is straight cut, a rib will be left along the centre of the work. The length of the side-cutting edges must not be overdone, and, where the profile is deep, it is more

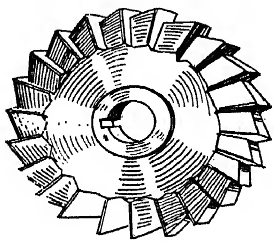


Fig. 137.—*A side-and-face cutter which is made in a range of standard widths and diameters. They are often used in pairs or gangs separated by distance pieces.*

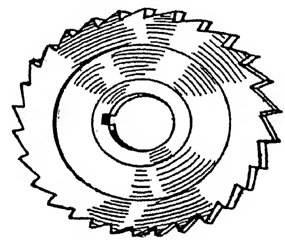


Fig. 138.—*A slotcutter which is made in various standard widths.*

satisfactory to break the cut into two operations by means of separate cutters.

Slender Cutters.—Slender cutters of a special nature are best if made in toothed form. After making, the blank teeth may be milled in the correct manner, but a satisfactory and quick method is to file them with a half-round file to the shape shown in Fig. 133. (This remark is intended to apply to small cutter making and where ready facilities for cutting by other methods are lacking.) The centre in the cutting end should be as large as possible in diameter, but at the same time not carried to a sufficient depth to cause weakness.

Different Types of Cutters.—Cutters of the types so far described, and which, to accomplish the work in hand, must be made in such a form that the cutting end terminates in a sharp point, will prove unsatisfactory in use. Therefore, where such

a condition arises, recourse should be made to a different type of cutter. The most simple form in which a suitable alternative cutter can be provided is shown in Fig. 134. The mandrel is driven in the machine, with a fly cutter of suitable profile projecting above the surface. As regards clearance, the tool should

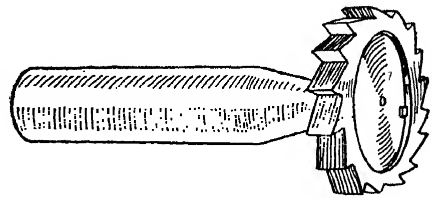


Fig. 139.—A special type of cutter made for cutting Woodruff key seats.

be treated in the same manner as if it were to be used for a boring operation. Another type of flat cutter which will perform an endless variety of jobs is shown in Fig. 135. A feature possessed by such a cutter is that all of the milled surfaces can be machined with it so that they will be parallel to each other at one setting. Where the section to be milled is such that a "necked" cutter like that shown is required, take care when designing the cutter not to make the narrow portion too weak to withstand the "spring" of the front part when undercut. Cutters having parallel bores are intended to be used in a horizontal milling machine, and are made in various sizes to suit standard mandrels. Such cutters are clamped on to mandrels between distance collars, and where heavy cuts are to be taken, "cutter slip" is checked by means of a key.

Roller Cutters.—The type shown in Fig. 136 is what is known as a roller or cylindrical cutter, and its use is confined to purely surfacing operations. Where sufficient power is available, and the teeth so arranged

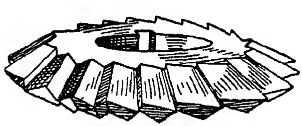


Fig. 140.—An angle cutter.

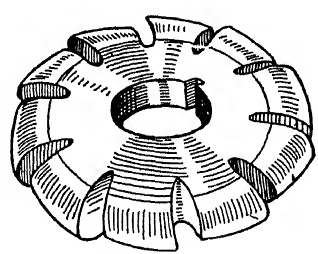


Fig. 141.—A convex cutter form relieved to give radial clearance.

provide plenty of ship space between them, extremely heavy cuts can be taken.

That shown in Fig. 137 is a side-and-face cutter. Such cutters are made in a range of standard widths and diameters. As may be gathered, they cut on the sides as well as the face, and therefore will machine vertical faces equal in height to the distance from the edge of the teeth to the centre boss. They are often used in pairs or gangs separated by distance pieces of approximate width to machine both opposite vertical faces of a part at one setting.

Slotting Cutters and Slitting Saws.—Slotting cutters are made in various standard widths, so that they will cut a slot of the required size in one cut. A cutter of this description is illustrated in Fig. 138. Binding of the cutter in the slot is prevented by the fact that the sides are hollow ground. Cutters which are intended for metal sawing are given clearance in this manner, and can be had in a very wide range of different thicknesses.

An example of an angle cutter is shown in Fig. 140. This particular cutter is called a double-angle (equal) cutter, and can be had in angles of 45°, 60°, and 90°. Single-angle cutters are made right and left handed, in angles of 45°, 50°, 60°, 70°, and 80° right hand, and 30°, 40°, and 45° left hand.

Double-angle cutters having unequal angles are used chiefly for gashing or fluting spiral cutters, and are made with one side always at 12° and the opposite side at 48°, 53°, 58°, 63°, 68° or 73°.

Form-relieved Cutters.—Cutters which are form-relieved to give radial clearance maintain the same profile throughout the length of their grinding life. A convex cutter of this type is shown in Fig. 141. Resharpening is carried out by grinding the faces of the teeth, but for the shape produced by the cutter to remain constant, the front of the teeth, after grinding, must always be on a radial line. Besides the shape illustrated, they are also made in other shapes, notably concave, right- and left-hand corner rounding, and double-corner rounding, and as standard can be obtained to give radii from $\frac{1}{16}$ in. and upwards.

Cutters for special purposes such as twist-drill and reamer fluting, thread milling, and gear cutting are also made in the same manner.

Cutters for milling gear teeth can be obtained for producing $14\frac{1}{2}$° involute, 20° stub, and epicycloidal gears, and also for cutting both roller and silent chain wheels.

General Considerations.—As may be imagined, these cutter are expensive, and unless any one particular cutter is likely to have a considerable amount of use, a fly cutter can often be

pressed into service for a "one-off" job. The question of expense from the amateur's point of view can be relieved by using a cutter-bar holder containing a tool in lieu of a side-and-face cutter of large diameter. The bar, a piece of flat mild steel, can be bored at one end to fit the mandrel and slotted at its outer end to receive a tool bit at an angle of 45°. The end of the tool is ground to a 90° point, and is arranged to project beyond the side and end of the bar. A separate tool will be required for right- and left-hand working, but to meet these conditions the bar can be reversed on the mandrel.

Woodruff Cutters.—A special type of cutter is made for cutting woodruff key seats, like that in Fig. 139. These cutters are made in sizes to correspond with the standard keys, and are not expensive to buy. On this account they are extremely handy for general use in carrying out small milling operations in the lathe, and they lend themselves to slight modification for special purposes.

Owing to the ready manner in which this type of cutter can be held, it provides, in the long run, the easiest way of making small special cutters for lathe use. There is one objection to making cutters integral with the shank, and that is, the fact that it is in some cases not easy, if at all possible, to cut teeth on the back face of the cutter, but this objection can be overcome by tapping the centre of the cutter and making the shank with a screwed spigot.

SMALL TAPS, DIES, ETC.

Small tools are an essential part of all mechanical engineering equipment, whether the work engaged upon is large or small. The uses for them are, however, greater in smaller work and jobbing work in general, for whereas in the prototype parts are of such dimensions as to permit being machined by lathe or borer, the same parts in the model, owing to small-scale reduction, call for different treatment as regards machining, and the mechanic is therefore forced to rely upon the use of small tools to perform the same operations.

Such tools include drills, reamers, dies, taps, and all kinds of cutters, and it is proposed to deal with the various types, their uses, methods of using, and keeping in condition. Although many of the tools are standard productions, it frequently happens that a tool or cutter of a special nature is required. As a matter of fact, in many cases the use of a special tool, even for jobs that may be regarded as machinable by other methods, is desirable

on account of accuracy and time saving, particularly where several identical articles are wanted. While it is true that in most instances, providing that a certain amount of discrimination has been used regarding the machining treatment, the time saved will more than compensate for that lost in making the tool or cutter, in others the intricate character of the work may make the use of such cutter indispensable.

Threading Dies.—Of all small tools, the greatest diversity of types or patterns occurs in those used for the production of screw threads. Included among these are engineers' pattern, ring, solid, button or acorn, spring, chaser, and full-mounted types. Of the adjustable dies, different makes of ring dies vary as to the method of adjustment.

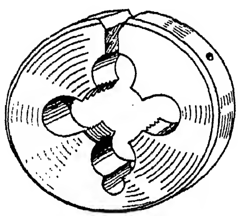
Engineers' Pattern.—These dies, although still manufactured, are what may be described as an old-fashioned type. They offer certain advantages, inasmuch as they withstand severe service, and also the amount of adjustment (over or under size) is practically unlimited. A full thread cannot be cut at one screwing, and in use the adjusting screw is slacked back to permit the rod or part being screwed entering completely between the halved dies. After closing the dies hard on to the job, the thread is run on for the required distance and wound back to the start again, further cuts being taken until a full thread is formed. Oil is used as a lubricant for steel, and as the thread approaches complete formation, it is advisable to break the chips by occasionally reversing the direction of rotation as the die is being fed downwards, in order to prevent portions tearing out. It may be mentioned that the front of the dies are relieved, and this is the part where the cutting take place. Also the dies are assembled in the stock in such a manner as to permit both sets of markings to line up. After much use, the leading edges of the thread lands become rounded, and can be restored by careful grinding and stoning. Special dies are comparatively simple to make. A pair of tool-steel blanks slightly larger than the patterns are made to fit the stock. Secure in position, and drill a correct-size tapping hole (exactly equal to the core diameter of the thread) through the centre of the blanks on the parting line. Proceed to finish as for a ring die as regards lead, tapping, land, and relief, but file the butting faces to length after tapping and reproduce the cutting edges and chip spaces on these faces to the pattern.

Ring Dies.—The pattern shown in Fig. 142 is known as a ring die. These may be either solid or split for adjustment, but with both types a full thread is produced at one screwing, and

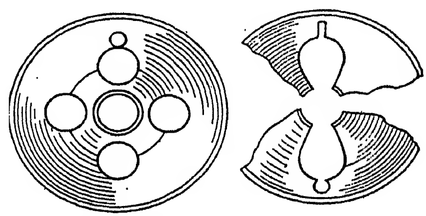
where split, the amount of movement obtainable is only sufficient to permit a thread being produced within a few thousandths either way of correct size. As previously mentioned, various methods of obtaining the adjustment exist, but in all cases the difference lies only in the manner in which the slot is opened and closed.

Where the adjuster is incorporated in the die, it is in the form of a taper pin or screw acting in the slot or jack screw tapped through the side of the die and bearing on the opposite wall of the slot to force it open. Dies in this class are tempered, so that the natural spring of the tool steel tends to close the slot when the adjuster is removed.

The die illustrated requires provision to be made in the holder for the purpose of effecting adjustment. This may be in the



Figs. 142 and 143.—Two views of a split ring die.



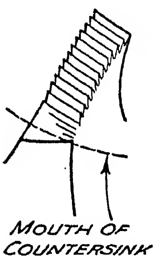
Figs. 144 and 145.—(Left) The die blank drilled. (Right) The holes elongated to provide "spring."

form of three screws passing through the side of the holder, the centre one, being pointed to an angle of 60°, seats into a countersink in the mouth of the slot and the other screws, arranged at an angle of 45–60° on either side, are flat ended. Pressure applied by the centre screw opens the slot, and the side screws, locking down on to the edge of the die, maintain the adjustment under cut. Naturally, when a closing action is necessary, the adjustment is effected by slightly withdrawing the centre screw and tightening the side screws.

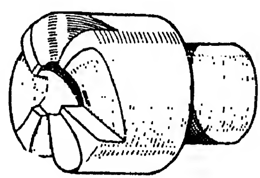
Ring dies are obtainable as standard in the commonly used thread systems—Whitworth, B.S.F., B.A., Metric, etc. The dies are made in several sizes as regards outside diameter, in the following range: $\frac{5}{8}$ in., $\frac{13}{16}$ in., 1 in., $1\frac{7}{16}$ in., $1\frac{1}{2}$ in., etc. The maximum size of thread that the dies in each range will cut is restricted by the diameter of the die, and this point requires watching when purchasing; as, for instance, the largest size of thread in the 1-in. diameter range is $\frac{1}{2}$ in. diameter. While such

a die is suitable for thread correction or running-down purposes, it is, in the author's opinion, too weak to give reasonable service (particularly if the thread form is deep) for thread cutting, and the next larger size should be selected. The most popular range of dies for threads up to $\frac{1}{4}$ in. diameter is the $\frac{13}{16}$ in. size, and for a set of Whitworth, small sizes or B.A. threads are the handiest.

If a greater range is required, say from $\frac{3}{16}$ to $\frac{1}{2}$ in. diameter, it is preferable to use two different diameters of die to cover the range, as the die holder will be too massive for sensitive control on the small sizes. In use the die must be started true with the work, or a drunken thread will result, and a lead filed truly on the end of the bar will greatly assist in this direction. Care must be exercised in attempting to correct the die for squareness with the work by applying unequal pressure to the stock handles, as



Figs. 146 *and* 147.—(*Left*) *Backing off for die "lead."* (*Right*) *Button die.*



if only one or two threads have been cut, the mouth of the die is very liable to chip badly. Once this has happened, the die is ruined for cutting clean threads.

When the cutting edges become dull after repeated use, a certain amount of resharpening can be done in the larger sizes with a round oilstone and in the smaller sizes by lapping. This is done by filing down a suitable piece of brass rod to such diameter that it will seat on both flanks adjoining the thread in the chip slots. The lap thus formed is suitably driven and charged with grinding paste. Each cutting edge is dealt with in turn by passing the chip slot over the lap and applying pressure to the die to force the lap towards the centre.

Making Special Ring Dies.—A cast-steel blank is prepared in accordance with the size of the die in use. When drilling the tapping hole, select a drill that will allow the tap to cut a full thread, and see that it is drilled square with the face of the blank, Fig. 143 showing this first stage. Carefully tap the hole, and with a centre drill countersink on one side until the mouth of the hole

equals the diameter of the thread. The reverse side is also countersunk, but only slightly to break the sharp edge and run the tap through again to remove any burrs. Now refer to Fig. 144 before commencing the next stage. This operation consists of drilling the holes to form the chip spaces which break the thread up into the cutting edges.

The blank shown is drilled with four holes for this purpose, but the actual number will depend on the size of the tapped hole in the blank. This is a point that may be explained in the following manner: to provide ample strength and to ensure that the finished die will cut freely, the finished thread lands (width of thread left standing between the gaps) are made proportionate to the diameter of the thread in close approximation to the ratio of 1 : 4. Thus the lands of a die to cut $\frac{1}{4}$-in. diameter

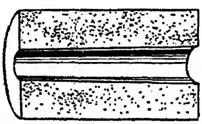


Fig. 148.—Blank for hollow mill.

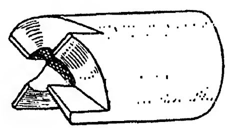


Fig. 149.—Hollow mill for cutting brass.

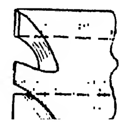


Fig. 150.—Hollow mill for cutting steel.

thread would be about $\frac{1}{16}$ in. in width. With a thread that is larger in proportion to the outside diameter of the blank, it might not be possible to drill four holes large enough in diameter to give a sufficiently narrow land, in which case five holes may be drilled. On the other hand, where the thread is small, it may be more advantageous to drill only three holes of larger diameter. When this course is adopted, it is not always necessary to drill the "spring" hole, and in the case of $\frac{5}{8}$-in. and $\frac{13}{16}$-in. dies having three holes, the aim should be to leave the wall of the die with a minimum thickness of $\frac{3}{32}$ in.

However, in all cases the procedure is the same, and will be dealt with on the lines of Fig. 144. After selecting a drill that will give what is required, mark off and drill four equally spaced holes on a pitch-circle diameter that will bring the edges of the holes very nearly into the top of the thread. Immediately below one of them drill a smaller hole for springing. Next elongate the chip holes with a fine round file until they run into the thread sufficiently to give the correct land, as shown in the lower half of Fig. 145. Saw a slot opposite to the spring hole from the inside,

extending to within $\frac{3}{64}$ in. to $\frac{1}{32}$ in. of the edge. The small bar of metal that is left acts as a tie, and will do much to overcome distortion while hardening. As the actual cutting of the thread takes place on the mouth of the die, it is necessary to relieve the countersunk portion of each land to form a cutting edge. Do this by filing the rear edge of each lower than the front with a suitable-sized fine crossing file. An enlarged view (Fig. 146), which, by the way, is for a right-hand die, will explain what is meant better than test, but avoid doing this operation with a round file, as a weak tooth will result.

Harden and temper in the usual way, and draw the temper farther to a dark blue behind the spring hole by holding the die against a red-hot piece of bar iron. The bar at the top of the slot is removed by grinding on the corner of a sharp wheel. The foregoing remarks apply equally as well to solid dies in which the slot is omitted.

Button Dies.—Another form of die is seen in Fig. 147, and is a type very suitable for lathe use. The blank is made to the shape shown, and is held on the small diameter. The thread extends for a depth proportionate to the corresponding sizes of ring dies, the back of the tapping hole being counterbored to clear the thread. After tapping, the teeth are filed on radial lines. Follow the same rules regarding land and relief given for ring dies. Button dies have an advantage in the fact that they are easily sharpened by grinding on the flat face of each tooth. A left-hand die is cut in the opposite direction to that shown.

Spring Dies.—Spring dies are a varied form of the above type, the difference being that the blank is tubular. The teeth are cut deeper and are supported at the front by an encircling split collar. While possessing the properties of the former type, these have an added advantage in the fact that adjustment is obtainable through the agency of the split collar.

Full Mounted Dies.—Made in the larger sizes only, these dies themselves are similar to engineers' pattern, but each pair of dies is mounted in a round collet, at the bottom of which is a guide accommodating the correct diameter of material screwed. This guide serves to keep the dies in line and square with the rod. The thread is cut in one screwing, and adjustment is by means of a screw bearing on the end of each half die.

Chaser Type.—Usually mounted with a guide also, this type of die is provided with four flat chasers. All of the chasers adjust simultaneously by means of a coned ring operated by two pairs of screws. Here again is a type which covers only the larger threads.

Hollow Mills.—One of the most ticklish jobs on a lathe is that connected with the turning of small diameters, and where the length of the work in proportion to the diameter is great, it becomes, by ordinary means, an extremely difficult task. It is such jobs as the making of small special bolts, screws, or parts of a similar nature, where the use of a suitable hollow mill will be invaluable. As its name implies, the hollow mill is really an end-milling cutter with a hole through the centre. The size of the cutter is determined by the centre hole, a $\frac{1}{8}$-in. diameter cutter producing work of that diameter. In use, the cutters are held in line with the work and fed on to it, the work only revolving. To start the cutter it is essential to taper the end of the bar to an included angle of about 60°, the front end of the taper being made slightly smaller than the size of the hollow mill. For preference the tapering is done with a cutter similar to a

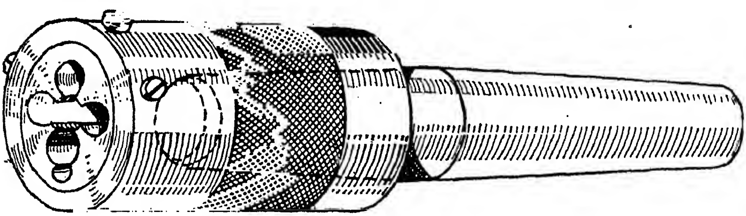
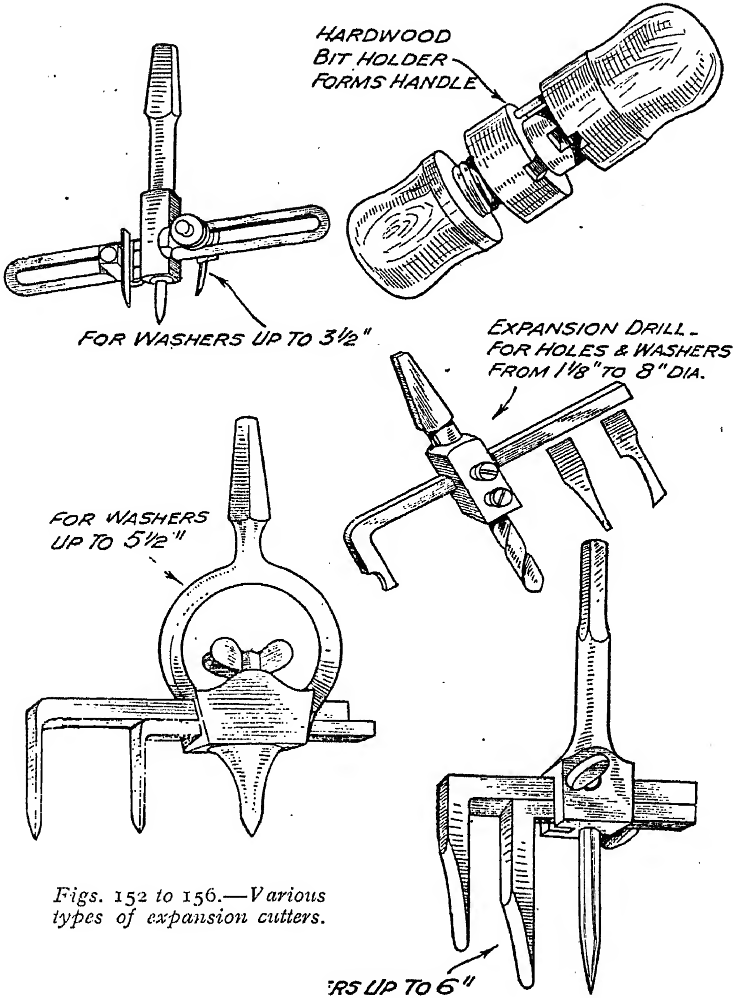


Fig. 151.—A useful die holder.

hollow mill, with the teeth arranged round the face of a 60° countersink. Resharpening is carried out by stoning the front edges of the teeth, which should have a back slope of 5°. If grinding becomes necessary, the cutting edges must all be level when finished, but excessive grinding will increase the cutting diameter, as the hole is back tapered.

Making Hollow Mills.—The largest special hollow mills likely to be required can be made from blanks $\frac{5}{8}$ or $\frac{3}{4}$ in. diameter × 1 or $1\frac{1}{4}$ in. in length respectively. Turn and face the blank, and at the same setting drill the centre hole slightly smaller than the required size. Taper ream from the back with a standard $\frac{1}{4}$ in. per foot taper reamer, until the small end or front is opened out to correct size: Fig. 148 shows a blank in section. Mark centre lines across the face at right angles to each other. Cut the teeth, according to the nature of the material to be worked, straight fronted for brass as in Fig. 149, or with a rake of 10° for steel as in Fig. 150, the fronts of the teeth in both cases being



Figs. 152 *to* 156.—*Various types of expansion cutters.*

smoothly finished on the radial lines. File the backs of the teeth to leave parallel lands $\frac{1}{16}$ in. wide, and back off at 5°. Harden and temper in the usual way, and stone the fronts and tops of the teeth.

Holder for Dies and Hollow Mills.—A useful holder for making small bolts and screws on a centre lathe is seen in Fig. 151. A plain plug is turned taper at one end to fit the tailstock, a hole being drilled in the front end to clear long pieces. The holder portion is bored to slide on the plug and counterbored in the front to take a die or hollow mill. Time will be saved by having a separate holder for each class of tool.

In use a piece of bar is held in the chuck, and the end tapered as described. Feed the hollow mill with the tailstock screw until the required length has been stripped down, the knurled body being held while so doing. Slide the hollow mill and holder off the plug, and substitute the die and holder. Again holding the knurling, the die is fed forward by sliding along the plug, and when the face of the die is approaching close to the shoulder, the holder is released and allowed to run round with the work. Such an attachment on small work will pay for the work involved.

HOW TO APPLY FOR A PATENT

An application for a patent, stamped £1, may, in an ordinary case, be accompanied either by (*a*) a Provisional Specification (no stamp), or (*b*) a Complete Specification, stamped £4. It is usual to apply with a Provisional Specification, the advantages being the small initial cost and the opportunity for working out details, which latter may be incorporated in the Complete Specification to be filed at any time within the following twelve months (or thirteen months with extension fee), assuming the applicant wishes to proceed. If, however, the invention is fully developed, then a Provisional Specification may be dispensed with and a Complete Specification may be filed straightway. Complete Specifications of mechanical and electrical inventions require, usually, to be accompanied by drawings.

The Patent Office (Southampton Buildings, Chancery Lane, London, W.C.2) does not require a model, but if time and other circumstances permit, it is often advisable for the inventor to construct one so that he may be in a position to describe in his specification the best form of his invention known to him.

The Patent Office does not make any search, as to novelty, on Provisional Specifications, but only on Complete Specifications. If time permits, it is generally advisable to have a search made before applying for a patent.

FILES AND FILING

While the production of accurate surfaces by filing, particularly in restricted openings in thickish material, is only likely to result after considerable practice, many inaccuracies are created by employing the wrong type of file for the job in hand. Therefore, a brief description of the various grades and shapes of files, together with some of their uses, will be given.

Types of Files.—The commonest types of files are those known as hand, flat, half-round, round, square, and three-square. Hand and flat files are both rectangular in cross section, the difference between them lying in the shape of the blank. Hand files are parallel in width, but are thinner at the point, or end, than in the centre, whereas flat files are tapered from the centre to the point in both width and thickness. An indication of the section of the remainder may be gathered from their names, that of the "three-square" being an equilateral triangle. In the same class as hand and flat may be included mill, pillar, and warding files. The first is generally made parallel throughout its width and thickness, but it is proportionately thinner than the hand variety by about one-third, also it is cut in a different manner. Pillar files may be regarded as narrow hand files, and the warding type is similar in shape to a flat file, the difference being that it is equal in thickness throughout the length.

Round and Square Files.—These are made in two distinct forms, taper and blunt. The latter type are equal in section throughout. Another form of three-square file is made for saw sharpening. This differs from the ordinary type in the following manner: the file diminishes gradually in size from heel to point, and the three corners are radiused. Further, a portion of the file is left blank at the point, the teeth being single cut and extending round the corners.

The term "half round" as applied to files is somewhat misleading. Actually the curved face of the file represents an arc of about 120° of a circle. There is, however, a file made that may be described as being truly half round. This is the "pit-saw" type. Unlike the half round, these files are made in the "blunt" form, and are single cut. As may be gathered, they are primarily intended for sharpening a certain kind of saw, but are also extremely useful in other directions.

Differing from the "half round" in one point, namely, the front is also curved, but to a lesser degree than the back is another type, which are known as crossing files. Cant files are

triangular in form, the proportions of the triangle being such that the base is equal to and the point the same height as a corresponding section of a half-round file.

Knife files, while being proportionately similar to warding files, are tapered from one edge to the other, so that the section is wedgeshaped like a knife blade. Feather-edged files are tapered from the centre towards both edges in this manner. Various other special sections are obtainable, but these, or a modification of them, will cover most requirements.

Used to a large extent in place of ordinary hand and flat files on account of their free and rapid cutting properties, are a brand of files known as " Dreadnought." These files are easily distinguished by the tooth form, which, instead of being straight and arranged diagonally, are semicircular in shape, the tooth spaces being machined, i.e. cut away from the blank ; the teeth appear very coarse in pitch in comparison with ordinary files.

For finishing convex or hollow surfaces, there is a special kind of file available. These are known as " rifflers." They are usually made double-ended, and in effect represent short round or half-round files which have been curved at the ends by bending.

Sizes and Grades.—All of the files mentioned, with but few exceptions, are made in a range of lengths commencing at 4 in. and increasing by increments of 2 in. up to 20 in. These lengths do not include the length of the tang or drawn-out portion to which the handle is attached. The files are also made in different cuts or pitches of teeth. Regular lines are made in four cuts, these being bastard, second cut, smooth, and dead smooth. The pitches of the teeth in any one particular cut do not agree throughout the range ; thus, the teeth of a 4-in. hand file are finer than those of a 12-in. of the same grade and shape.

Saw files are made in second cut only, and mill files in smooth as well, but both of them are single cut, the teeth being cut across the blank at an angle. All of the other ordinary files mentioned are double cut, the teeth being lightly overcut in an opposite direction, so breaking up each tooth into a series of jagged edges. File teeth, by the way, are raised up from the metal with a tool shaped like a cold chisel, and this, as may well be imagined, was at one time a process carried out entirely by hand.

Swiss Files.—For fine, accurate work, there is a range of what are known as Swiss files. These are made in ten different lengths, ranging from 2 in. to 10 in., also in ten cuts. Unlike the files previously mentioned, the degree of cut is in this instance referred to by numbers. These run from numbers 00, 0, and 1 to No. 8.

Those with the coarsest teeth, No. 00, are approximate to a bastard cut, while No. 8 is extremely fine.

Shapes approximate to those of ordinary files are to be had, together with other shapes, such as "Barrette," which are similar to a cant file, but cut on the widest face only, and "pippin," which in section have the shape of an apple pip. The general appearance of these files is clean, that is, the edges and corners are sharp, and their use on profiles requiring really sharp corners makes a marked difference in the quality of the work.

Files similar in quality are those known as needle files. These are not tanged in the ordinary sense. The file blanks are produced from steel wire. This is formed to the required section at one end, and the remaining portion is left as it

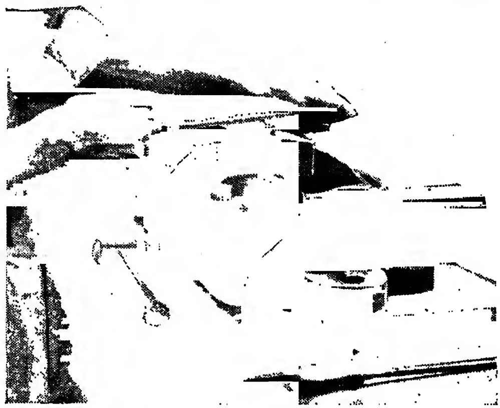


Fig. 157.—Showing the method of holding a file for flat filing.

Fig. 158.—The top face of the jaws should be set at a convenient height, which may be gauged by standing erect with the elbow in the position shown.

is, to provide a means of holding or attachment to a handle. Such files are made in several lengths, but those of the various shapes in each length are made from the same gauge material. Consequently, they may conveniently be held in a handle fitted with a chuck or setscrew.

Safe Edges.—Hand files are, as standard,

made with one safe edge, that is, one of the narrow sides has no teeth cut on it. The object of this is that, when filing against a shoulder, the safe edge of the file is kept adjacent to it, thus preventing "cutting in" on that side. Square files are also made in this manner, having one or more safe edges, but not as standard.

Where a particular shape of file is not readily obtainable, ordinary files may be modified in various ways in order to make them suitable for the purpose. This is chiefly done by grinding extra safe edges or reducing the width to permit working in narrow spaces where a smaller file would be too flimsy.

For filing large surfaces, the end of a file is sometimes cranked to permit the handle to clear the surface of the work. To do this it is necessary to heat the file, and in so doing care must be taken to prevent the heat travelling up and drawing the temper from the cutting portion. Round and half-round files are sometimes heated and bent at the ends to serve as rifflers. This means rehardening, which, if carefully carried out, is satisfactory, but seldom will a file so treated stand up to prolonged use.

Handles.—The question of handles is an important one, particularly when heavy filing has to be done. Thus bastard files of reasonable size should be fitted with handles of such a diameter and shape as to afford a comfortable grip, free from any suggestion of cramping. Common file handles of wood, and suitably ferruled, are quite satisfactory, although there are various types of special handles which offer certain advantages, and are mostly of a non-splitting character. There is also a special holder made which enables an ordinary hand file to be used on large surfaces without the necessity for cranking the end. Whatever type of handle is used, care must be taken to see that it is a rigid fit when in position. This is most necessary if accurate work is to be produced.

Filing.—The first point to receive consideration should be the vice. This should be of such a size that it will hold the largest work likely to be handled. It is an important point that the top face of the jaws is set at a convenient height. This may be judged by standing erect with the elbow in the position shown in Fig. 158, the vice being packed up to the correct height.

For small work a small vice may with great convenience be used in conjunction with a larger one. The small vice is mounted on a piece of plate, to the bottom of which is attached a piece of hexagonal steel bar 3 or 4 in. in length. This shank may then be held in various positions in the larger vice. The method of holding a file for flat filing is seen in Fig. 157. Normally the

handle is gripped in the right hand with the thumb upwards, the point of the file being held between the ball of the thumb and the fingers of the left hand. If the surface is a rough one, or there is much metal to remove, a bastard-cut or Dreadnought file is used.

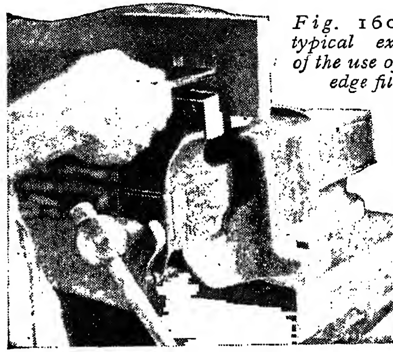


Fig. 160.—A typical example of the use of safe-edge files

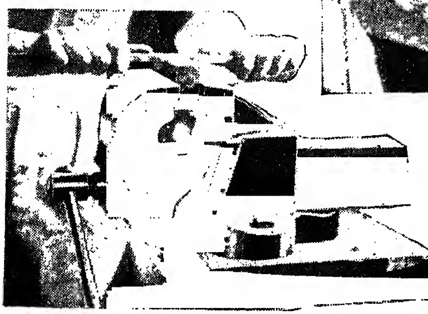


Fig. 159.—Narrow surfaces are finished by draw filing, the file being drawn backwards and forwards along the work as shown.

The filing is carried out in a diagonal direction, and the pressure which is applied on the forward stroke is reduced on the return stroke. After a time the direction of filing is reversed, this having the effect of taking off the series of ridges left by the file when travelling in the opposite direction. The filing is continued in alternate directions until the work is close to the required size. Care must be taken to see that the file is kept moving in a horizontal plane. At first there is, however, a general tendency to raise the right hand on the return stroke and the left hand on the forward one. The effect of this is to produce a surface anything but flat, and is a condition to be corrected by practice. Carry on the filing with a second-cut file to remove the marks left by the previous one, and finish with a fine file. Fine files are liable to pick up pieces of metal in the teeth, with the result that the surface of the work is deeply scratched. This clogging can be obviated by cleaning the file and filling the teeth with chalk. Narrow surfaces are finished by draw filing. The file is held and drawn backwards and forwards along the work, as seen in Fig. 159, a " straight-line " finish resulting.

A typical example of the use of safe-edge files is shown in Fig. 160.

MARKING OUT FOR MACHINING

A certain amount of marking out is required on most machining jobs, with the exception of perhaps purely cylindrical work that is finished when it comes from the lathe. Other items may require drilling, surfacing, slotting, or keyways in them before completing, and the positions of details in relation to previously machined surfaces are more often than not a matter of small importance.

The essential tools are a surface gauge or scribing block, a good stiff steel rule, small dividers, square, scriber, and a centre punch. A small angle bracket is useful under certain conditions, when one or two clamps will also be required for use in conjunction with it. A simple form of scribing block consists of a reasonably heavy circular base, the underside of which is machined and recessed so that it will lay flat without rocking, and capable of sliding freely on a flat surface. This base supports a vertical spindle upon which slides a split boss carrying a scribing needle, the needle being locked by the action of tightening a knurled nut. The setting of the point of the scriber is dependent on trial and error or lightly tapping the scriber, when only held friction tight, in the

Fig. 161.—An efficient type of scribing block and universal square.

desired up or down direction. A scribing block of the type shown in Fig. 161 is much more desirable for fine work. The spindle of this is connected to a rocker bar which has a screw adjustment at the rear end. After setting the point of the scriber approximately and locking it tight, it is corrected by tilting the bar to raise or lower the point by means of the knurled adjusting

screw. It is necessary to have a flat surface on which to rest the work while marking off. Failing a proper machined surface plate, a square of plate glass makes an efficient substitute for light work.

Coating for Marking Out.—To make the marking easily visible, it is usual to coat the surface of the work to be carried out. Bright steel is coppered for this purpose by rubbing on with a piece of rag a solution made by dissolving copper sulphate crystals in water with the addition of a few drops of sulphuric acid. This is kept in a bottle for use as required. The steel must be clean and free from oil, otherwise coppering will not result. Wipe the surface dry immediately, and if the marking out is to be retained on the work for several days, rub over with oil to fill the lines and prevent them from rusting. Cast or forged surfaces are prepared by chalking over.

Marking Out.—Supposing that it is necessary to mark lines on a machined face, one $\frac{27}{32}$ in. away from a machined edge and another one $\frac{29}{32}$ in. away from it, a rule is held vertically against

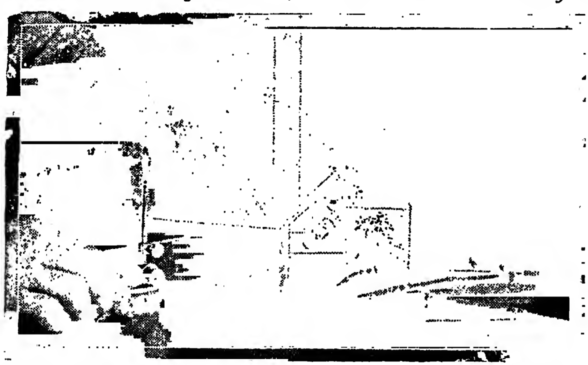


Fig. 162.—To produce a straight line, draw the needle along the surface of the work so that the point is trailing.

the face of an angle bracket or square block, so that the end of the rule is touching the surface plate. The point of the scriber is then adjusted against the markings on the rule to the first dimension, and the job to be marked is laid down on the machined edge and a line made on the face of the work. Fig. 161 shows the method of setting the scriber. The second line, being $\frac{29}{32}$ in. away from the first one, is $1\frac{3}{4}$ in. away from the base, to which dimension the scriber is then set. Draw the needle along the surface of the work so that the point is trailing, as in Fig. 162.

INCREASING TO FULL SIZE

Fig. 163.—*How to square off with the dividers.*

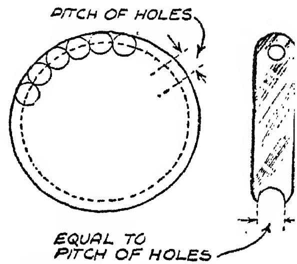


Fig. 164.—*Marking out and cutting large holes.*

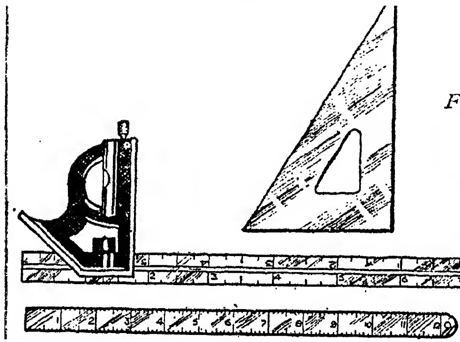


Fig. 166.—*Adjustable square, steel rule, and set square.*

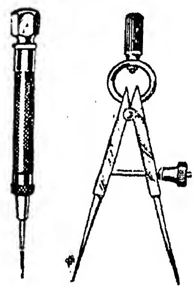
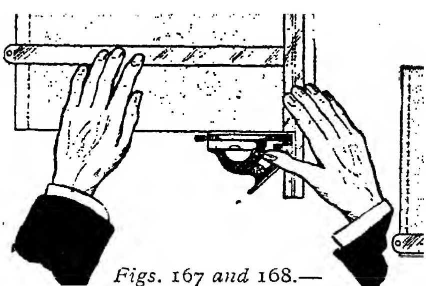
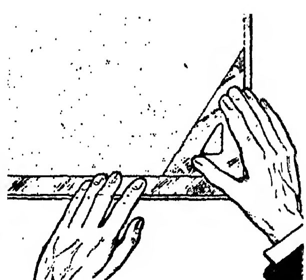


Fig. 165.—*A group of essential marking-out tools.*





Figs. 167 *and* 168.—*Marking out and squaring up and (left) using the square.*

This will produce a straight line. If the needle is presented square to the work, a " jumping " action takes place, with the result that the line is wavy. Where the rule in a combination square is used, a slightly different procedure may be adopted. After making the first marking, slide the rule upwards in the head of the square until a fair line is reached, when the scriber is raised the required distance. This is particularly useful when the dimensions are in odd sixty-fourths, and when it is apt to be confusing to count up from an odd fine marking.

Use of the Vee Blocks.—Vee blocks are essential for cylindrical work. For most work of this nature it is essential that

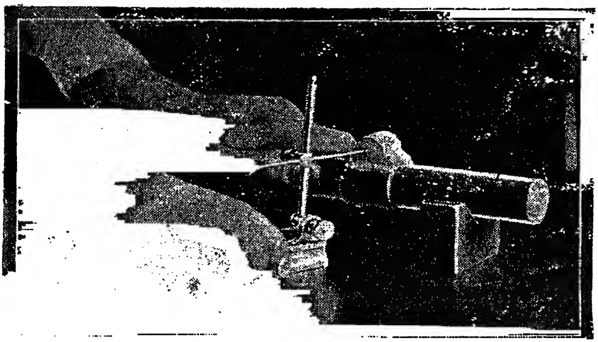


Fig. 169.—*The casting being marked out above is to be drilled through the boss at a definite distance up from the centre hole.*

the dimensions are worked from the centre line of the bar. To find the centre of a shaft by this method, lay it in the Vee blocks, and set the end of the scriber near enough central ; make a short line on the end of the shaft, or, in the case of a tube, at each edge ; turn completely over, and make another mark parallel to the first one, resetting the point of the scriber exactly between the lines. If the lines are fairly wide apart, a further trial is made ; if not, the marking is continued along the bar as required, and firmly continued on the end, if necessary, for further reference.

The casting being marked out in Fig. 169 is to be drilled through the boss at a definite distance up from the centre hole. This is done by mounting the job on a mandrel, the centre of which is found in the manner stated. The height of the centre is noted by placing the scriber point against the rule, and the distance that the hole is to be above centre added to it.

Using the Angle Brackets.—Work that has a machined face or boss, but that requires marking out in a direction in which there is not a machined surface to rest it upon, has to be clamped to a false vertical surface for the purpose. The casting in Fig. 170 is such an instance, and which calls for the use of an angle bracket and clamp. Having been previously machined on the base, the casting is clamped with this face against the face of the bracket, one side of the casting being squared up with the surface plate. The centre of the slot in the rough casting is found by transferring the height of the edges to the rule, and the dimensions worked from a point midway between.

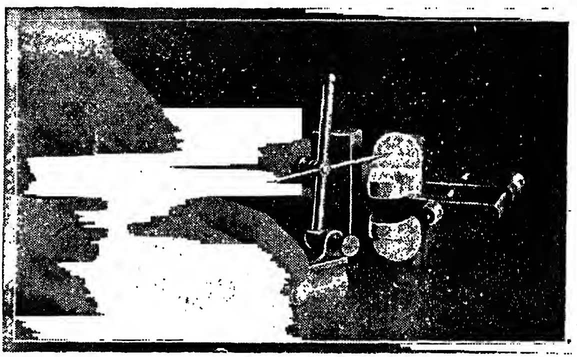


Fig. 170.—Work that requires marking out in a direction in which there is not a machined surface to rest it upon has to be clamped to a false vertical surface for the purpose.

Rough Castings, and Forgings.—Rough castings and forgings that are to be marked out for facing or other machining, and on which there are no previously machined surfaces, are packed up so that the important points on the casting lay level with the plate. This can be checked by using the bent end of the scriber as a gauge. When level, a line is scribed at the distance down to which the machining is to be carried.

Not infrequently it is necessary to mark off from the centre of a rough cored hole, to do which it becomes necessary to stop the hole up in a temporary manner to provide a centre for the dividers. This can be done by wedging a strip of hardwood across the mouth of the hole.

Holes that are to be bored on the face plate are set up to a scribed circle.

LATHE TOOLS AND TOOL ANGLES

At no time is the importance of correct tool grinding in respect of lathe tools more appreciated than when the only power available for driving the lathe is by treadle, or is otherwise only sufficient to do the job when conditions are almost ideal. Naturally, when work is being roughed out, the object is to remove the surplus material in the minimum amount of time, and unless the right tool is used for the job in hand, this will not be so. Then again, finish is to a very great extent dependent on the tool itself, and as the tool must alter, particularly as regards "rake," for different materials, it is not surprising that proficiency in tool grinding is usually the result of long experience.

It is, therefore, proposed to give particulars of what is considered the best range of tool shapes for general use, together with grinding angles for different materials. You must, however, understand that others of a special nature may be wanted from time to time as occasion arises.

Many of the tools illustrated may be ground from bar material of appropriate section, or for that matter filed up prior to hardening. Where the latter practice is adopted, care must be taken that the filing is done in such a manner to allow the tool to be ground after hardening, that is to say, do not file "top rake" with a small round file, for instance, as it will be difficult to grind this portion of the tool on a standard wheel.

Section of Steel.—Before proceeding farther, a word on the steel used may not come amiss. Where solid tools are used, it is better to have a steel as deep in section as possible. Thus, if the tool post will accommodate a tool $\frac{1}{2}$ in. high, use that size in preference to, say, $\frac{3}{8}$ in. Generally speaking, rectangular-sectioned steel will make "handier" tools and, while making for rigidity, will be no more costly for material than square tools of the lesser height. The rectangular sections referred to run as follows: $\frac{1}{2} \times \frac{3}{8}$ in., $\frac{5}{8} \times \frac{5}{16}$ in., $\frac{3}{4} \times \frac{3}{8}$ in., and so on, and are obtainable in both carbon and high-speed varieties. High-speed steel tools are the most advantageous, even for amateur use, but unfortunately the steel is comparatively expensive. The most economical way to use high-speed steel is in "tool-bit" form in a special holder or to use "tipped tools." This type of tool consists of a shank of carbon steel to the end of which is brazed or welded a comparatively small piece of high-speed steel in a suitable position. Tools such as these are now relatively cheap, but are not to be had in small sections.

Cutting and Clearance Angles.—The tool illustrated in Fig. 171 is marked to show the cutting and clearance angles. Before proceeding farther, it will be as well to state that, even though properly made and ground, a tool cannot function correctly if improperly set; that is to say, the bottom face of the tool must be set in a horizontal plane. Where the lathe is fitted with a "rocker-bar" type tool post, it is easy to overlook this point, but it must be remembered that the effect of rising or dipping the nose of the tool to obtain correct centre height so that the bottom face is not lying parallel with the cross-slide is to alter the front-clearance and top-rake angles. Thus, if the base of the tool is rising towards the front, the front-clearance angle is decreased and the top rake increased in relation to the work. If rising towards the back, the clearance is increased and the top rake diminished.

The tool shown in Fig. 171 is a right-hand tool—that is, it cuts towards the chuck and produces the right-hand side of the work as turned. The front-clearance angle is the angular amount that the front of the tool slopes out of perpendicular. Top rake is the amount of back slope from the nose of the tool; side rake is the amount that the top of the tool slopes away from the direction in which the tool feeds along the work. The tool is also ground on both sides to give side clearance.

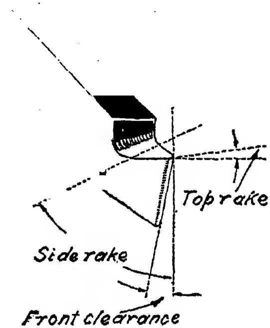


Fig. 171.—The tool shown is marked to show the cutting and clearance angles.

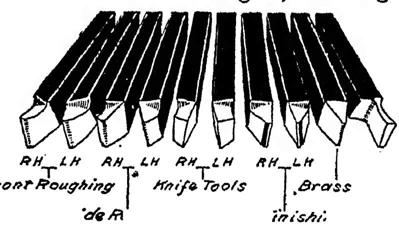


Fig. 172.—The group of tools shown may be made from a bar without forging.

Therefore, if the tool is laid flat on its base, the top edges of the ground portion would be clear of the bottom if tested with a square.

The Relationship of Tool to Material.—As a general rule, the variation in front and side clearance is only very slight, but the top and side rake must be altered considerably

effectively to machine different classes of material. For soft mild steel the top and side rakes may be at their greatest, meaning that the cutting may form a very acute angle. Tougher material like nickel and such steels as cast steel require machining with tools of less rake, on account of the fact that very keen-edged tools will not stand up to them. Therefore, the harder the material the more the rake is reduced, to afford strength to the cutting edge. Brass and cast-iron tools are rather different. Tools for hard brass, at all events, are made flat topped to check digging tendencies, whereas with iron the rake is reduced to provide a cutting edge that will withstand the abrading action of the metal for the greatest time. The group of tools shown in Fig. 172 may be made from the bar without prior forging. Their uses are as follows.

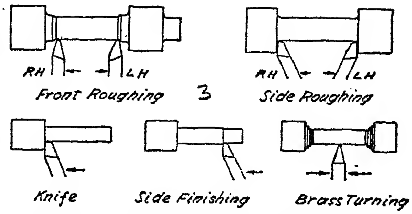


Fig. 174.—When the long cutting edge is presented square to the work, the front face has a back slope of 5°.

Front Roughing Tools.—General roughing out, turning, or facing, particularly suitable for tough material and cast iron. Fig. 174 shows method of application to bar work, the arrows showing direction of feed for right- and left-hand tools. For slender work the radius at the nose should be made small. Both top and side rakes.

Side Roughing Tools.—For general turning of a shouldered character when set at an angle as shown in Fig. 174 or when set square with the work, for rapid removal of mild or soft steel. When so used, the "swarf" or shaving comes away over the tool clear of the work. Use with a deep cut and medium feed. In profile, the nose of the tool should form an angle of a few degrees less than 90, the corner being radiused. Both top and side rakes.

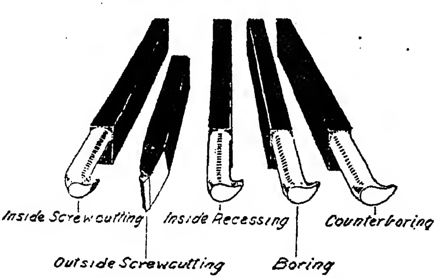


Fig. 173.—Outside and inside screw-cutting tools.

Knife Tools.—Chiefly used for work-

ing with mild steel. The tools are made in such a manner that when the long cutting edge is presented square to the work, the front face has a back slope of 5° (see Fig. 174). Deep cut, fine feed. Side rake only.

Side Finishing Tools.—Like a knife tool, excepting that a small flat is stoned on the front square with the direction of travel, the object being to obliterate feed marks such as are produced by pointed or fine round-nosed tools. Light cut, fine feed. Slight top rake and side rake. In a different form may have a wider face and top rake only for use with coarse feed. They then require very careful setting to be successful.

Brass Turning.—The small, round-nosed brass tool is suitable for machining hard brass, gunmetal, and the like. Used for roughing out and turning as in Fig. 174, and can be fed in either direction. Flat topped, no rake.

Outside and Inside Screw-cutting Tools.—Both made with top and side rake. Front clearance of inside tool as for boring tools. Main cutting should be done on leading flank of tool by feeding top slide along slightly, as well as increasing depth of cut. Allow both flanks to cut on last one or two cuts to obtain correct thread form. Representative tools are shown in Fig. 173.

Boring Tools.—Also shown in Fig. 173 are three boring tools, their respective uses being shown in Fig. 174. The round-nosed tool is suitable for straight-through holes, and has top and side rakes. The counterboring tool can be used for boring into corners or flat bottoming. Has both top and side rakes. The recessing tool is suitable for cutting oil channels in bushes or bearings, or such jobs as cutting clearance recesses for internal screw cutting. Made with top rake only. Feed in direction of arrow.

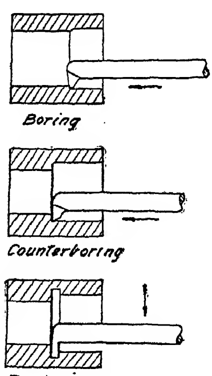


Fig. 174.—Methods of using the round-nosed tool, the counterboring tool, and the recessing tool.

Feed and depth of cut for boring will depend on the rigidity of the shank of the tool, but the types of tool shown are more suitable for light duties. Rather than increase the front clearance to prevent interference by rubbing, the clearance face should be reduced in depth by grinding away at the bottom in a manner similar to that shown.

The table on p. 111 gives tool-grinding and coolants fc

Parting Tools.—The purpose of the parting tool is for cutting off or grooving. It is

essential that the blade of the tool be made wider at the cutting edge to prevent binding as the tool is fed into the work. Where top rake is required, it must not be made excessive on account of weakening the tool. It is preferable to grind the rake by holding the tool vertically against the face of the grinding wheel to reproduce a concave surface equal to the radius of the wheel.

Tool-grinding Angles

Material.	*Tool-grinding Angles.*			*Coolant or Lubricant.*	*Cutting Speed in Feet per Minute.*	
	Clearance.	*Top Rake.*	*Side Rake.*		*Carbon-steel Tools.*	*High-speed Steel Tools.*
Mild steel .	8–10	8–10	20	Suds or Oil	40	80
Three per cent. nickel, annealed .	6–8	5–8	10–12	Oil	20	45
Tool steel .	5–6	5	10	Oil or Turps	20	40
Grey cast iron	6–8	5–8	10–12	Dry	30	60
Hard cast iron	5–6	2	5	Dry	10–15	30
Hard brass .	10–12	None	None	Dry	65	130
Soft brass .	8–10	5	15	Dry	45	80–90
Hard-drawn copper .	8–10	5–8	15	Dry or Suds	40	80
Aluminium .	8–10	5–8	15–20	Dry or Paraffin	80	160–180

Tool angles and cutting speeds may require modifying to suit conditions (see p. 117).

To convert cutting speeds in feet per minute to revolutions per minute, find inches per minute by multiplying given speed by 12, and divide by circumference of work in inches.

TURNING BETWEEN CENTRES

Work of a shaft-like character that requires machining all over is finished between the centres. The work having previously been centred up, and where necessary roughed out as already described, remove the chuck from the nose of the lathe and fit the catch plate. Of the two centres supplied with the lathe, the live one, or the one that fits into the headstock, is the soft one. One other point: this centre when in position must run perfectly true on the coned portion. It is obvious that, if this is not so, when the work has been finished at one end and turned round to finish the opposite end, the two sets of machined surfaces will not be concentric.

A good plan is carefully to clean the taper hole in the nose of the lathe and clean the fitting end of the live centre. Put the centre in position and lightly tap home with a soft mallet. Start up the lathe and make absolutely sure that the centre runs true. Should any doubt on this point exist, set the top slide round to 30° and lightly skim up the nose of the centre, finishing it off smoothly. Then make a small dot on the front of the nose of the lathe and a dot immediately opposite on the centre. Where a sleeve is fitted, this should also be marked. These dots are then lined up each time the centres are used, and this simple precaution will ultimately save a lot of time.

Fig. 175 shows a short shaft mounted between the centres. A suitable carrier is attached to one end of the work, the tail on it engaging with the driving pin in the catch plate. The centre of the tailstock end must be well lubricated. At this point mention is again made of the importance of clean centres in the work. This applies to the smoothness of the countersink, the angle of same in relation to the nose of the lathe centre, and adequate clearance at the bottom of the countersink. Where the holes have been drilled with a combination countersink drill, no trouble (providing that the short drill at the front has not been unduly reduced in length by grinding) will be experienced. Otherwise a small pilot hole should have first been drilled and opened out with a 60° countersink, leaving a little of the original pilot hole at the bottom.

A common fault is to drill a shallow pilot hole and open out at the front with a twist drill. Even with careful grinding, an indifferent centre will result, and owing to lack of a good bearing the countersink will wear quickly as the turning progresses. There is no guarantee that this wear will be even and, therefore,

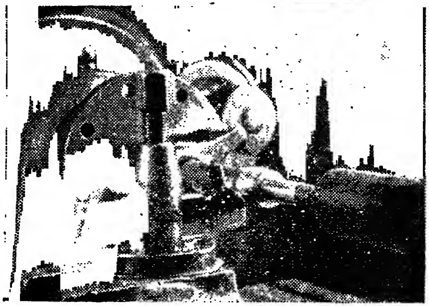


Fig. 175.—Showing a short shaft mounted between the centres.

Fig. 176.—Most lathes are made with a set-over tailstock, adjustment being made by turning a screw as shown.

Fig. 177.—Sharper tapers are formed by adjusting the top slide round to the required angle and operating by hand.

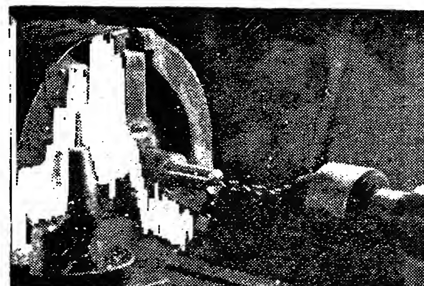


Fig. 178.—Carrying out a drilling operation.

different portions of the job may run out of truth with each other. When the pilot-hole is drilled too shallow so that the point of the centre touches the bottom of it, oval work will be produced.

Setting the Lathe to cut Parallel.—Where long portions have to be turned between the centres, a slight misalignment of the centres in relation to the ways of the bed will make itself noticeable by the tapering of the work. Most lathes are made with a set-over tailstock, adjustment being made by turning a screw as shown in Fig. 176. Where the small end of the taper is at the tailstock end, the centre is moved in a direction away from the tool or vice versa. Although a datum line is usually made on the adjoining edges of the fixed and movable portions of the tailstock, the coincidence of these lines will seldom ensure that the lathe is going to cut parallel, owing to the slight lateral movement that is almost bound to occur when the tailstock is locked to the lathe bed. Unless the centres are aligned with a test bar and indicator, it is usually a matter for trial and error to get the cut parallel over a respectable length.

General Remarks.—Long, slender work will require additional support, either in the centre by means of a fixed three-point steady or by a travelling steady operating behind the cut. Where a fixed steady is used, a true track is first turned for it near the centre of the shaft or bar, and when a travelling one is used it must be adjusted up to the work each time that a fresh cut is taken.

After finishing the work at one end, insert a brass pad under the end of the carrier screw to prevent it damaging the finished turning. For the same purpose, when one end has been screwed, put a nut on to the thread to form a carrier hold. Sometimes it is desirable to finish light work without having to reverse it end for end. This can be done by square centring the driving end with a square 60° punch after centre drilling in the usual way. A special square centre in the headstock provides the means of driving. This is only suitable, however, for light operations, but is a method which is extremely useful on certain classes of work.

Taper Turning.—In the same manner that the tailstock can be adjusted for cutting parallel, so it can be for the production of slow tapers. This applies only to work that is held between the centres. Sharper tapers are formed by adjusting the top slide round to the required angle and operating by hand as shown in Fig. 177. The production of accurate tapers is not an easy matter, and is an item that cannot be dismissed after such a casual reference; but as this is a subject which falls into an advanced stage, it will be dealt with at length later on.

Drilling.—Small bush-like and hollow parts not made from cored castings are roughed out internally by drilling and finished by boring, or drilled and finished by reaming. In Fig. 178 a drilling operation is being carried out. After facing and centring the front of the work, drill a pilot hole first where the hole is to be a large one. It is not advisable to carry out drilling operations after finishing the work externally. First rough the outside down to within reasonable limits of finished size, and carry out any drilling, reaming, or boring afterwards. When this is not done, more often than not it will be noticed that, after finishing the hole, the roughed-out portion does not run true with the bore, hence the advice. Also when producing "thin-walled" parts, the drill is apt to expand the metal slightly, and even if the job does not move a fraction during the drilling, refinishing externally becomes necessary.

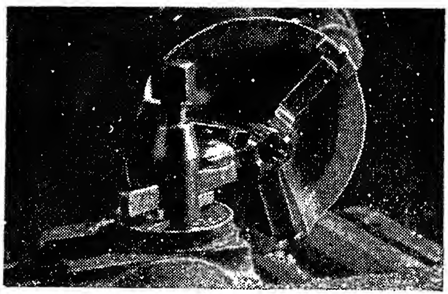


Fig. 179.—The parting tool shown has a specially sectioned blade ground throughout its entire length.

The remarks regarding the alignment of the tailstock apply also to drilling and reaming. Particularly is this so when deep holes are to be drilled, as, if the drill has to be sprung into the centre when started, the resultant hole will most likely have "run" in its length. Sometimes it may be necessary to drill very long holes right through a shaft or bar. Where this length exceeds that of the drill, the drilling is done from each end.

In such cases and where a true hole is required, true the bar up in the four-jaw chuck, gripping it by ½ in. or so. The outer end of the bar is then supported in the fixed steady so that it runs true throughout. After drilling as deeply as possible, reverse the job and drill from the other end.

Parting Off.—So much depends on the tool when cutting off by this method that the points concerning the tool will be dealt with first. In the first place, the width of the tool should be in proportion to the size of the lathe. With a solid tool see that the side clearance is accurately ground in relation to the base of the tool. The sides of the tool are also made slightly back, tapering from the nose.

To a large extent, the front clearance controls the rate of feed, so that the angle of this should not be made too great. For brass leave the tool flat topped, but for steel grind a slight top rake by holding it against the radius of the grinding wheel. Set the tool exactly right for centre height and feed in slowly. Use plenty of lubricant for cutting steel, and see that the chips are coming off clean. If they have a rough appearance, the tool will most probably break before it has penetrated to any depth.

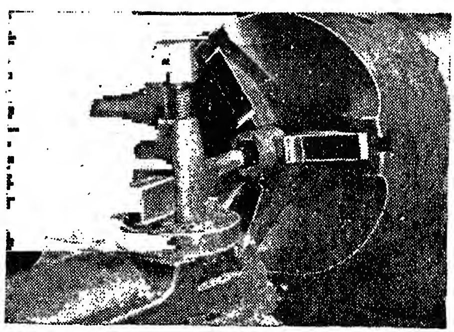


Fig. 180.—*A solid-type boring tool in use.*

The parting tool shown in Fig. 179 has a specially sectioned blade ground throughout its entire length with the correct side and back clearances. Resharpening, therefore, is only required at the front or top to provide top rake. Another advantage of this type of tool lies in the fact that only a sufficient portion of the blade need be projected to suit the requirements of the work in hand.

Fig. 180 illustrates a solid-type boring tool in use. This is only one form in which boring operations may be carried out, and this is dealt with later.

Tab needs

Ft. per Min.:	15	20	25	30	35	40	45	50	60	70	80
Diam. in.	Revolutions per Minute.										
$\frac{1}{16}$	917·0	1223·0	1528·0	1834·0	2140·0	2445·0	2751·0	3057·0	3668·0	4280·0	4891
$\frac{1}{8}$	459·0	611·0	764·0	917·0	1070·0	1222·0	1375·0	1528·0	1834·0	2139·0	2445
$\frac{3}{16}$	306·0	408·0	509·0	611·0	713·0	815·0	917·0	1019·0	1222·0	1426·0	1630
$\frac{1}{4}$	229·0	306·0	382·0	458·0	535·0	611·0	688·0	764·0	917·0	1070·0	1222
$\frac{5}{16}$	183·0	245·0	306·0	367·0	428·0	489·0	550·0	611·0	733·0	856·0	978
$\frac{3}{8}$	153·0	204·0	255·0	306·0	357·0	408·0	458·0	509·0	611·0	713·0	815
$\frac{7}{16}$	131·0	175·0	218·0	262·0	306·0	349·0	393·0	437·0	524·0	611·0	699
$\frac{1}{2}$	115·0	153·0	191·0	229·0	268·0	306·0	344·0	328·0	459·0	535·0	611
$\frac{5}{8}$	91·8	123·0	153·0	184·0	214·0	245·0	276·0	306·0	367·0	428·0	489
$\frac{3}{4}$	76·3	102·0	127·0	153·0	178·0	203·0	229·0	254·0	306·0	357·0	408
$\frac{7}{8}$	65·5	87·3	109·0	131·0	153·0	175·0	196·0	219·0	262·0	306·0	349
1	57·3	76·4	95·5	115·0	134·0	153·0	172·0	191·0	229·0	267·0	306
$1\frac{1}{8}$	51·0	68·0	85·0	102·0	119·0	136·0	153·0	170·0	204·0	238·0	272
$1\frac{1}{4}$	45·8	61·2	76·3	91·8	107·0	123·0	137·0	153·0	183·0	214·0	245
$1\frac{3}{8}$	41·7	55·6	69·5	83·3	97·2	111·0	125·0	139·0	167·0	195·0	222
$1\frac{1}{2}$	38·2	50·8	63·7	76·3	89·2	102·0	115·0	127·0	153·0	178·0	204
$1\frac{5}{8}$	35·0	47·0	58·8	70·5	82·2	93·9	106·0	117·0	141·0	165·0	188
$1\frac{3}{4}$	32·7	43·6	54·5	65·5	76·4	87·3	98·2	109·0	131·0	153·0	175
$1\frac{7}{8}$	30·6	40·7	50·9	61·1	71·3	81·5	91·9	102·0	122·0	143·0	163
2	28·7	32·2	47·8	57·3	66·9	76·4	86·0	95·5	115·0	134·0	153
$2\frac{1}{4}$	25·4	34·0	42·4	51·0	59·4	68·0	76·2	85·0	102·0	119·0	136
$2\frac{1}{2}$	22·9	30·6	38·2	45·8	53·5	61·2	68·8	76·3	91·7	107·0	122
$2\frac{3}{4}$	20·8	27·8	34·7	41·7	48·6	55·6	62·5	69·5	83·4	97·2	111
3	19·1	25·5	31·8	38·2	44·6	51·0	57·3	63·7	76·4	89·1	102

BORING

When boring holes from the solid, the work is first prepared by drilling a pilot hole and enlarging it to within reasonable limits of the size required, before commencing the actual boring. This is done by opening the hole in steps by means of suitably sized drills. Where the hole can be roughed out beyond the range of the largest drill available, a cutter can be utilised for the purpose. Such a cutter can be made with a mild-steel shank, and several useful interchangeable hardened-steel cutters will enable a drilled hole to be opened out rapidly for finishing by one or two boring cuts. The pilot should be made an easy fit, with about $\frac{5}{1000}$ in. clearance, in say $\frac{1}{2}$-in. diameter hole, and case hardened. A 90° point on the locking screw engages with a countersink in the cutter. When making the cutters, the steel is cut off, and the countersink made in the centre of the cutter blank, turned to correct diameter in the holder, and backed off to suit the material being worked.

Boring a Hole.—An alternative method is to use a front cutter like that illustrated in Fig. 181, the side clearance being made sufficient to prevent rubbing. This type of tool is, however, unsuitable for deep roughening owing to "springiness."

To produce a good bored hole, it is essential that the cutting edge be rigid under working conditions. For this reason, select a tool or bar that is as near to the maximum size that the hole will

Fig. 181.—Where the hole can be roughed out beyond the range of the largest drill available a front cutter like that shown above can be utilised.

admit, with sufficient allowance, of course, to permit the back of the bar to clear when the cut is removed. When an "Armstrong"-type boring bar and holder are used, the bar should be allowed to project as little as possible beyond the front face of the holder.

When setting the tool for centre height, make sure that the heel of the tool will have enough clearance. Where the tool shows a tendency to set up chattering, the trouble can nearly always be overcome by narrowing the nose of the tool to reduce the area in contact with the work. It is most necessary to grind the tool to a fine shape, when either the shank of the tool needs to be small in proportion to the length or when the job being bored is of a thin character.

The failure of a lathe to bore parallel is nearly always due to incorrect alignment of the headstock spindle in relation to the track of the saddle. This is a fault that is easily rectified where the headstock is a separate casting, as jackscrews are mostly provided for adjustment, but in such cases where the headstock bearing housings are cast integral with the bed, the remedy lies in the direction of careful bearing adjustment.

Mounting Work on the Face Plate.—Where the work needs to be mounted on the face plate, and particularly when an angle plate is also used, it is most essential that the plate be balanced before commencing operations. Withdraw the driving pin connecting the back gear to the cone pulley, so as to leave the mandrel free to rotate in the bearings. The face plate will then come to rest with the heaviest point at the bottom. Opposite to this point and near the edge of the plate, a counterweight is attached. Change wheels form a ready means of providing the necessary compensation of balance, as shown in Fig. 182. Failure to balance the mounted work causes the lathe to run at an unsteady speed, a condition from which an oval hole will result.

Use of Pilot Bushes.—For holes that are deep in proportion to diameter, and for which an ordinary boring tool would be too flimsy, use can be made of a special form of bar which is supported at the front end. The boring bar is made of a length equal to about two and a half times the depth of the hole to be bored from a straight piece of finished material, such as silver steel. A true bush, having a hole in which the bar is a running fit, is fitted into the hole in the nose of the mandrel. The single-point cutter in the bar is held by a locking screw, and the distance that it is situated from the front end is such that the end of the bar enters into the bush before the cut comes on. The bar needs, of course, setting so that its axis coincides with that of the lathe

mandrel, and for this reason is more easily mounted in a special block. Such a block can be made by clamping a piece of suitably square metal in the tool post and making a reamed hole in it by means of tools held in the chuck. A setscrew passing into the hole holds the bar. It will be apparent that the cut must be adjusted by moving the cutter in the bar either by tapping or by means of an adjusting screw. Should a hole with a reamed finish be desirable, the hole is bored a few thousandths under size and finished with a floating cutter. Such a cutter is made double sided, measuring the size of the required hole over the cutting edges. The cutter is not fixed in the bar, but is left free to float. On this account, therefore, the hole in the bar is made either square or rectangular, the tool sliding in with perfect freedom but without slackness in any direction. It must be mentioned that prior to using such a cutter, the hole must be bored true, as the original hole acts as the guide.

Boring Work held on the Saddle.—The foregoing remarks have applied to work that can conveniently be held in the chuck or on the face plate. Work of an awkward shape or when the lathe will not swing in the ordinary way may often be handled by clamping to the saddle and operating with a boring bar between the centres. Provision is made on most centre lathes for doing this by means of Tee slots in the saddle. With "American"-type lathes, it will be necessary to remove the cross slide and

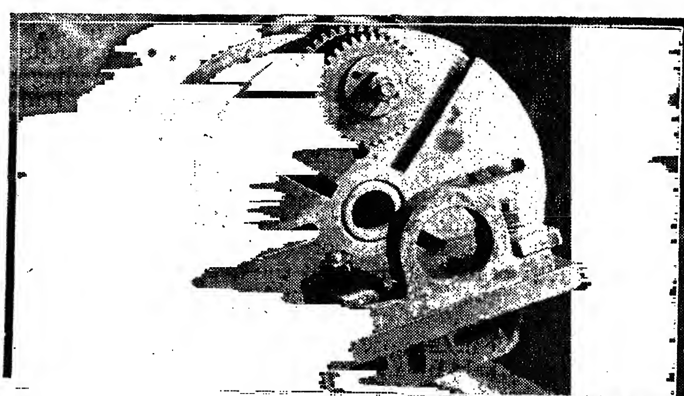


Fig. 182.—Change wheels form a ready means of providing the necessary compensation of balance.

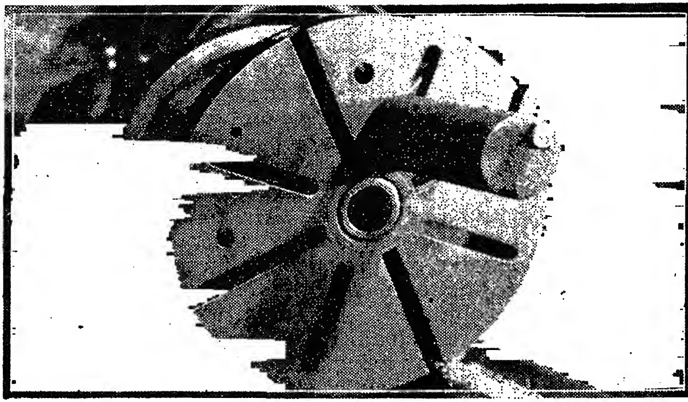


Fig. 183.—*Holes that are on the large size but of no great depth can be bored by means of a short bar mounted on the face plate.*

screw. The worst part of this class of work is the setting, and, therefore, a few instances of what are considered the easiest methods to employ will follow.

A long hole is to be bored from the solid through a boss-like formation in a casting having a flat base. First mark out the position of the hole centre on each end of the boss, suspend the casting between the lathe centres, and pack up the base of the casting level and clamp down. Drill a hole through the boss with a drill held in the headstock, and bore as described.

When boring a similar job with a cored hole, insert temporary hardwood ends into the cored hole, and mark a circle on each end of the casting concentric with the hole position. Remove the wood, and insert approximately the correct amount of packing beneath the base of the job, and test for correct position at each end of the boss with a bent scriber held in the cutter hole in the boring bar, adjusting the casting accordingly for height, or by movement crossways.

The third example deals with a job that needs to be bored through square with a previously machined face. For the purpose of mounting, an angle bracket is required. To set the angle bracket square on the saddle, lightly bolt it in position, and bring the vertical face to bear against the face plate. Pass a bolt through a slot in the face plate and through a slot near enough central in the angle plate, pulling the faces together with a nut. Finally tighten the angle plate to the saddle and release from the

face plate. This will ensure that the angle plate is lying square without having to use an indicator.

For boring operations the boring bar is centred at each end, and driven by means of a carrier and the work fed on to the tool by the sliding motion. Holes that are on the large size but of no great depth, such as in plate work or bosses on long levers, may be (by mounting the work on an angle plate) bored by means of a short bar mounted on the face plate, as in Fig. 183, or alternatively held in the chuck for smaller bores. The foregoing remarks regarding cutter adjustment and floating cutters again apply.

If, instead of fixing the bar direct to the face plate, provision is made to attach it to the top face of the tool slide, a sensitive tool adjustment will be obtained. By substituting a front tool in place of the tool bar, a machined surface surrounding the hole may be turned at the same setting. The cut is put on by running the lathe slowly in back gear and giving the feed handle a portion of a turn each time it comes round, or, as is sometimes done for the same purpose, a star wheel is attached in place of the handle to engage with a pin on the bed or saddle of the lathe. It should be pointed out that the slide is bolted flat on the face plate by the normal holding-down bolt holes.

Filling for Blowholes in Castings.—Frequently holes due to trapped gases during the casting process will be found in unimportant places (from the strength point of view), which detract very much from the appearance of the casting. These holes may be filled by using a thick paste mixed with water and including the following ingredients: sal-ammoniac 2 parts, flowers of sulphur 1 part, iron filings or borings 80 parts.

Etching Tools.—First warm the tool and coat it with beeswax at the part where you wish to etch the inscription or name. Next scratch the inscription into the wax with a steel needle or other pointed instrument, and then fill the incisions with sulphate of copper solution, a pennyworth of which will etch dozens of tools.

Whilst this will give a clear impression of the inscription, the latter is not permanent. If a permanent etching is required, the article should be coated with beeswax, the inscription scratched in with a sharp steel tool and filled with nitric acid. Use care with the latter, as it readily damages the skin.

SCREW CUTTING

The principle of screw cutting, that is, as understood by the term when applied to centre lathes, consists of gearing the lead screw to the headstock mandrel in such a manner that by revolving the mandrel one turn the lead screw will rotate sufficiently to carry the saddle forward a distance exactly equal to the pitch of the thread to be cut.

For screw-cutting purposes the saddle is generally connected to the lead screw by means of a lever-operated split nut. It will be apparent that to cut a thread of, say, 24 threads to the inch, the saddle and consequently the tool must travel a distance of $\frac{1}{24}$ in. for each revolution of the spindle. Thus, the factors governing the gearing ratio are—number of threads per inch required, and the number of threads per inch of the leading screw.

Lead screws are commonly cut either 8, 6, 4, or 2 threads per inch, but on the class of lathe that the reader is likely to use will not be finer than $\frac{1}{4}$-in. pitch. To cut a thread of 24 threads per inch on a lathe with a screw of this pitch, it will follow that while

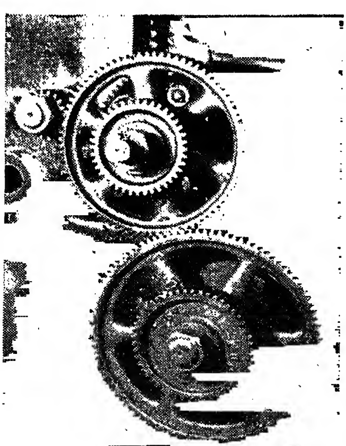


Fig. 184.—*Showing a simple gear train.*

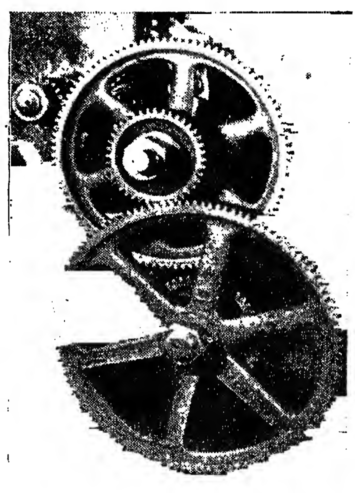


Fig. 185.—*A compound train. The gear behind the lead-screw wheel is used as packing.*

the mandrel is making one turn, the lead screw, in order to advance $\frac{1}{24}$th in., must revolve only $\frac{1}{6}$ of a turn—in other words, the mandrel must revolve six times as fast as the lead screw. Obviously, to do this the gear train connecting the mandrel to the screw must give a speed reduction of six to one.

Therefore, the first step in ascertaining which change wheels to use is to find the ratio of the gearing to employ by dividing the number of threads per inch to be cut by the number of threads per inch of the lead screw.

Change Wheels.—As supplied with the lathe, a set of change wheels may consist of 22 wheels, all identically bored and keywayed, ranging from 20 to 120 teeth, each wheel having 5 teeth more than the next smaller, one of the smaller gears, usually a 40, being in duplicate. With lathes having a lead screw of 6 or 8 threads per inch, the wheels may run from 24 to 100 teeth in increasing stages of 4 teeth.

Having found the ratio, all that needs to be done is to select a pair of wheels having numbers of teeth in the same ratio. As an example, what wheels are required to cut 20 threads per inch on a lathe having a lead screw of 4 threads per inch? 20 divided by 4 equals 5. The wheel on the lead screw, therefore, requires to have five times as many teeth as that of the spindle, or 100 and 20 teeth respectively. As these two gears run on centres that are fixed, some means is necessary to transmit the drive from one gear to the other. Provision is made for this in the slotted quadrant plate which is pivoted off the centre of the lead screw. Into the slot is fitted an adjustable stud, working on which is a bush having a key to suit the change wheels. Any convenient-size wheel is selected as an intermediate gear, and the stud is raised in the slot sufficiently to allow the wheel to pass on to the bush clear of the lead-screw wheel. A smaller gear is put on in front as packing, and locked by the nut provided; the intermediate wheel is then dropped into mesh with the lead-screw wheel and the stud locked in the slot, after which the quadrant plate is swung over until the gear engages the one on the spindle and locked. In Fig. 184 a simple gear train is illustrated. The top left-hand wheel represents the spindle and the lowest one the screw, the smaller wheels on the screw and in front of the intermediate or idler gear being used as packing.

Compound Trains.—Obviously, with the standard wheels, the limits of a simple train of gears are represented by a ratio of 6 to 1, 20 being the smallest gear available and 120 the largest: these, by the way, will cover all standard Whitworth pitches from $\frac{3}{16}$-in. diameter and B.S.F. from $\frac{5}{16}$-in. diameter up to the largest

size likely to be handled, without needing a compound train.

For finer pitches than 24 threads per inch, use will have to be made of compounding the gear train. If, for instance, a screw having a pitch of 30 threads per inch is required: $30 \div 4 = 7\frac{1}{2}$ to 1 ratio. To cut this with a simple train would require wheels of 20 and 150 teeth; as the larger size is not available, recourse is made to a compound train of gears. This

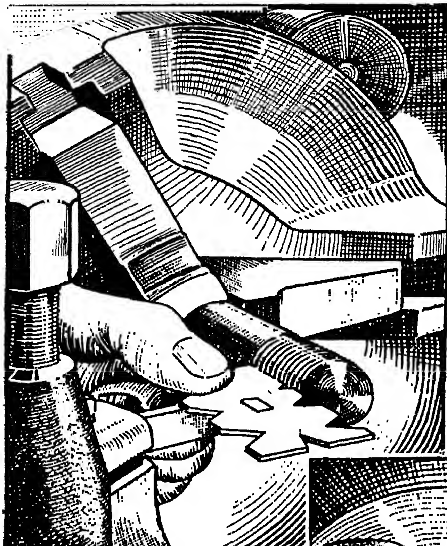


Fig. 186.—Setting the screw-cutting tool for centre height by means of a centre or screw-cutting gauge.

consists of splitting the gearing up into two units, as it were: one gear on the spindle drives a gear on the stud; a second gear, having a different number of teeth, is also mounted on the stud in front of the first, and by virtue of the key in the bush is driven at the same speed. This front or second gear meshes with the wheel on the screw.

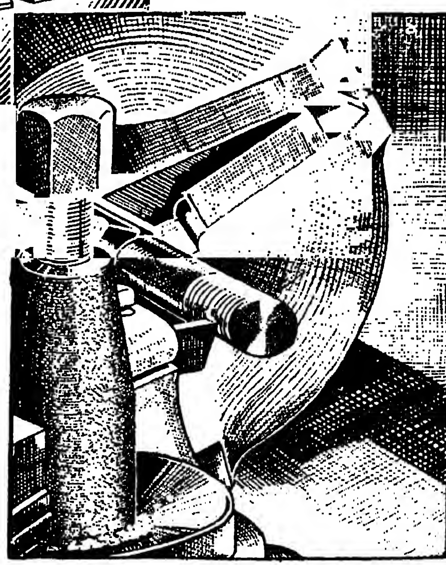


Fig. 187.—Cutting a thread.

Thus, by using a 20 wheel on the spindle to drive a 100 wheel on the stud, giving a reduction of 5 to 1, and the second wheel on the stud having 30 teeth driving a wheel with 120 teeth on the screw, a total reduction of 20 to 1 would be obtained. In the case under review, the gears could be split up into two trains to give a first reduction of $3\frac{3}{4}$ to 1 and a second of 2 to 1, or a first of $2\frac{1}{2}$ to 1 and a second of 3 to 1. To cut 30 threads, then, the following gears could be used: spindle 20, driving stud 75. Stud 50, driving screw 100; or, in the same order, 30, 75, 40, 120. This may be expressed as follows:

$$\frac{\text{Lead screw, threads per in.}}{\text{Threads required per in.}}=\frac{4}{30}=\frac{4\times1}{15\times2}=\frac{4\times5}{15\times5}\times\frac{1\times50}{2\times50}=\frac{20}{75}\times\frac{50}{100}$$

$$\text{or}\quad \frac{4}{30}=\frac{2\times2}{6\times5}=\frac{2\times20}{6\times20}\times\frac{2\times15}{5\times15}=\frac{40}{120}\times\frac{30}{75}$$

It will be seen that the numerator and denominator in each factor are multiplied by the same number to give suitable wheels, and further, either of the wheels indicated by the numerator may be used as a driver to driven wheels with the same result. Thus, in the last example 40 could drive the 75, giving a reduction of $1\frac{35}{40}$ to 1, and the 30 driving the 120, giving a second reduction of 4 to 1, so that $1\frac{7}{8}$ multiplied by 4 is equal to the $7\frac{1}{2}$ to 1 required. The examples instanced do not exhaust the possible combinations that could be used, and in selecting the gears, the only point to watch is that those selected will be large enough to permit meshing when the quadrant is swung into position.

A compound train is shown in Fig. 185; the gear behind the lead-screw wheel is used as packing. It is hoped that the explanation has made it clear that the working out of change wheels is only a question of simple mental arithmetic. For the benefit of those who have or may get a lathe having a change-wheel plate and are unfamiliar with the terms thereon, Spindle means the headstock spindle or shaft connected thereto by tumbler gearing, Stud is the stud on the quadrant plate, and Screw is the lead screw. Alternative markings, meaning the same things in the order named, are Spindle-driven, Driver-screw, or Driver-driven, respectively. In both cases, where only the first and last columns are marked, it means that only a simple train is needed, and as before stated, any wheel can be utilised as an intermediate.

Cutting a Thread.—Having turned the work ready for threading and mounted the wheels, set the screw-cutting tool for centre height and the flanks of the tool square with the work by means of a centre or screw-cutting gauge, as shown in Fig. 186; bring the saddle back so that the tool is well clear with the front of the

work. The nut is engaged with the lead screw and the tailstock locked hard up against the saddle to form a stop. A cut is put on, noting the position or reading on the cross-slide index. When the tool has travelled a distance along

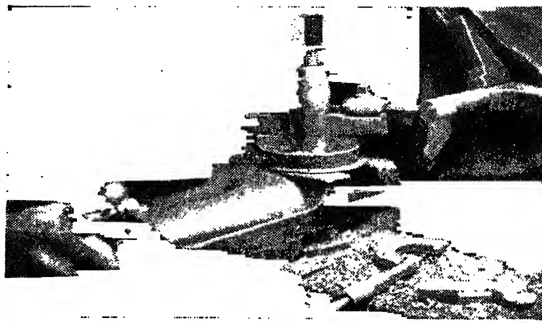


Fig. 188.—*The tool should be advanced several times during the cutting operation, as shown.*

the work equal to the length of thread required, disengage the nut, and at the same time recede the tool smartly. Return the saddle up to the stop and put further cuts on as before until the thread fits the female part. Fig. 187 shows a thread being cut, and it will be noticed that the tool is actually cutting and not merely scraping. During the cutting, particularly with deep threads, the tool is advanced slightly several times during the cutting operations, as seen in Fig. 188, but allowing the tool to cut all over on the last one or two cuts to obtain a thread of correct form.

Fig. 189.—*Showing the screw-pitch gauge in use.*

Where the thread washes out, as on a stud, care must be taken not to allow the tool to travel beyond the point of withdrawal on the previous cut, or the nose of the tool will break. Aim at withdrawing each succeeding cut slightly in advance of the previous one to obtain a gradual wash-out.

This procedure is adopted for all threads per inch that are multiples of the thread on the lead screw. When threads such as 9, 10, or 11 are to be cut, the nut is not disengaged, but the cut is withdrawn and the lathe reversed by pulling the belt backwards, or, when the saddle is first brought back against the stop and the nut engaged, a chalk mark is made on the face of the headstock cone or on the gearwheel, and a corresponding mark made on the front-bearing housing or gearguard. Similar lines are made on the lead screw and lead-screw bracket. The nut is disengaged at the end of the cut as before, and the saddle returned to the stop, which in this case is essential, and the lathe run until both sets of lines coincide at the same time when the nut is dropped in. It should be mentioned that to cut left-hand threads where the lathe is not fitted with a tumbler gear, two intermediate wheels will be required in a simple train and one intermediate wheel in a compound train. This is necessary to reverse the direction of the lead screw.

As distinct from the screw-cutting gauge referred to is the screw-pitch gauge illustrated in use in Fig. 6. Such gauges are made with serrated blades covering various screw pitches. The blades represent sections of threads of different pitches, and are correctly formed according to the standard represented, and on this account, apart from finding pitches, are useful for checking thread form when cutting.

Cutting Screws of English Pitch with Lathe having Metric Lead Screw.—If a wheel of 127 teeth is too large to use, use the ratio $\frac{2{,}160}{85}$ The ratio $\frac{127}{5} = \frac{2{,}152}{85}$ so the error per inch is less than 0·0005. The change wheels supplied with the lathe advance in fives from 20 to 120, and the pitch of the lead screw is 6 mm. These two items enhance the value of the quantity 2,160, as both 6 and 10 are factors of it. The 85 wheel is always placed on the lead screw, so the ratio which remains is $\frac{2{,}160}{6 \times N}$, N being the number of threads per inch. As an example, to cut 12 threads per inch, $\frac{2{,}160}{6 \times 12} = 30$, and wheels $\frac{45 \times 40}{60}$ give this value.

"Screw Thread Manual."—A companion work entitled "Screw Thread Manual," deals fully with all methods of screw-cutting, and gives tables of proportions of standard screw threads.

LATHE EQUIPMENT

It is not intended to take into consideration the method of driving the lathe, as it is concluded that the reader will understand that a bench type of lathe will require a separate foot motor or other means of driving.

Certain standard equipment is usually included with the lathe. This consists of a faceplate, catchplate, and centres. Additional equipment is sometimes included in the form of travelling and three-point steadies.

These items do not complete the list, as it is necessary to have chucks, tools, centres, and certain accessories for use in conjunction with the faceplate and catchplate, before every class of work can be undertaken.

The Faceplate.—This is a slotted circular casting the boss of which is machined to screw on to the nose of the lathe and the front face is machined perfectly flat. The face of this plate may be marked by a series of concentric circles, but where this has not been done it is as well to remedy the omission by lightly cutting the circles at intervals of ¼ in., commencing at the edge of the plate. These circles will serve as a guide for the placing and mounting of round work on the plate in such a position that a minimum of truing up only will be necessary.

While on the subject of marking, another line that may profitably be made on the plate is a centre line. If the plate is a small one and has been machined on the edge the line may be scribed firmly against the edge of a centre square. Where such a tool is not to hand, or the plate is large in diameter, a screw-cutting tool held on its side, with the point set at correct centre height against the point of the live centre held in the mandrel, may be used for scoring the line by bringing the tool to bear against the surface of the plate and winding it across by movement of the cross slide. The object of this line will be mentioned later. For holding the work on to the faceplate clamps will be necessary. These may be made from short pieces of rectangular steel bar with a hole drilled in the centre, but these are mainly objectionable in use owing to the tendency of the flat material to bend under the strain imposed by the bolts. Far more reliable are clamps of the drop-forged variety, two of which are seen lying on the surface of the plate in Fig. 190. Seldom are more than four of these clamps required to hold a job. The slots in the plate and clamps are made to clear bolts of a certain diameter, and a collection of good bolts and nuts of various lengths is required.

preferably in sets of four. See that the nuts are only just finger tight on the bolt threads before putting away ready for use.

The next item is an angle plate. This is also shown in Fig. 190. Angle plates are made in a variety of patterns, but for general use select one that is in keeping with the size of the faceplate and has unequal sides. The short side should for preference be radiused. The advantage of this will be found when it becomes necessary to set the plate a good distance below centre and when the edges or corners of a square-edged plate might perhaps project

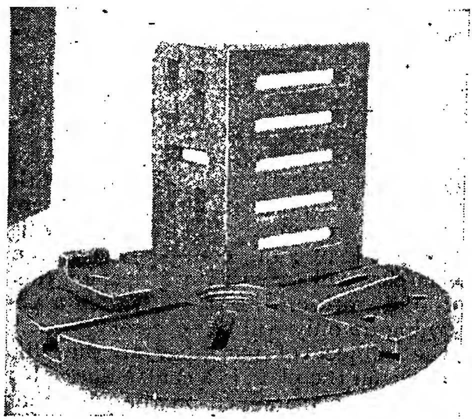


Fig. 190.—Clamps of the drop-forged variety, an angle plate and a faceplate.

over the outside of the faceplate by an amount sufficient to foul the bed of the lathe. The centre line on the faceplate mentioned previously will be used for setting the angle bracket for certain classes of work. Supposing that it is required to bore a hole, say, $1\frac{3}{4}$ in. up from a previously machined base—then the top or working face of the angle bracket is set at that distance below the centre and in consequence the centre line, already marked on the plate, will greatly facilitate this proceeding. In this manner the angle plate may be bolted correctly in position off the lathe and the job needs only to be moved in a sideways direction on the angle bracket when truing up.

Catchplate Centres and Carriers.—Work of the character of shafts or spindles is usually performed between the centres.

The catchplate which screws on to the nose of the lathe is provided with a driving pin to engage the tail of the carrier attached to the work as a means of driving it. Carriers of drop-forged steel are made in a variety of sizes. The type of carrier referred to is seen in the bottom right-hand corner of Fig. 191. The sizes of these run as follows: $\frac{3}{8}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, and $1\frac{1}{4}$ in., etc.; the dimensions are the largest diameter that each carrier will hold.

Steadies.—The travelling steady, where one is supplied, is used for the purpose of supporting long or slender work while turning between the centres. It is attached to the saddle by

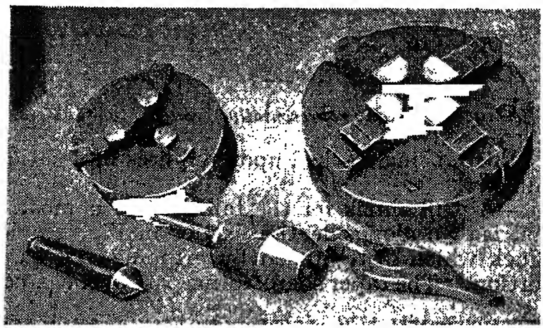


Fig. 191.—Showing carriers of drop-forged steel, a drill chuck for the tailstock, a conical lathe centre, and three- and four-jawed chucks.

bolts which fit into holes tapped on the side of the saddle. The actual steadying portion consists of a narrow hardened Vee block, which is adjusted on to the work, being arranged, in the case of a true shaft, so that the trailing edge of the steady is slightly in advance of the cut, or where the material to be turned is rough or not running true, slightly behind the cut. Naturally when this condition obtains the turning has to be started before the steady can be brought into position. In both cases the action of the steady is the same, namely, it prevents the work from pushing away from, or rising against, the tool.

The purpose of the three-point steady is mainly to support work that stands a long way out of the chuck when boring or internal screwing operations have to be performed in the end. The surfaces of the steadies which bear against the work are in many cases faced with bronze. Sometimes, however, this

material is steel or cast iron. Where this is so, pieces of leather or fibre must be introduced between the ends of the steadies and the surface of the work to prevent scoring or seizing. In any case

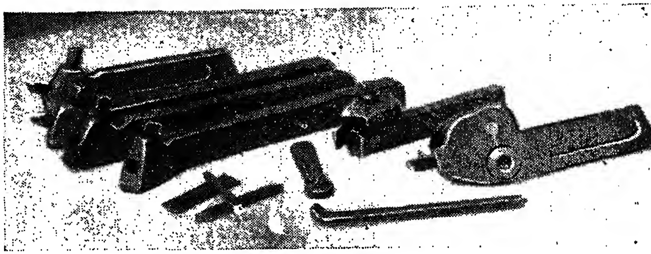


Fig. 192.—*A fairly representative group of tool-holders.*

the shaft or part being worked upon requires lubrication at the point of support.

Chucks.—A drill chuck for the tailstock is a most essential item. That shown alongside the carrier in Fig. 191 is a ball-bearing chuck which is tightened by gripping and turning the knurled portion. The taper shank forms part of the chuck in this

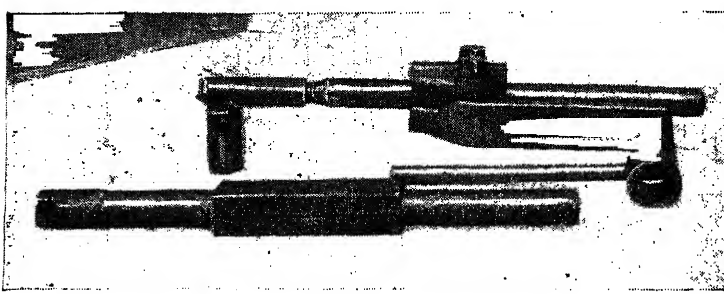


Fig. 193.—*Boring bars which employ tool bits.*

instance, and the shank fits into the taper hole in the end of the tailstock. Chucks of the " Almond " pattern tighten by means of a key, shaped like a bevel pinion, which engages with a toothed ring on the chuck. These chucks are not supplied complete with shanks, although the shanks, finished to standard tapers, may be purchased separately.

The Geared Scroll Chuck.—Perhaps the most useful chuck of the lot is a three-jaw geared scroll chuck. This, as represented in the top left-hand of Fig. 191, is the standard pattern. Two sets of jaws, one set being stepped in the opposite direction to those shown, and a key are included. The four-jaw independent chuck opposite to it has jaws which are reversible. Such a chuck is essential to properly hold irregular-shaped castings and plates for facing. No provision is made in the form of threads in the chucks themselves for the purpose of screwing on to the lathe nose. A fairly representative group of holder-type tools is seen in Fig. 192. These holders hold short lengths of square high-speed steel; three of these "tool bits" are seen in the front of the photograph. They are supplied in a hardened condition and may be quickly ground to any shape. The tool on the left is a spring screw-cutting tool, and the holder can be rendered rigid by tightening the large screw with the hexagonal key. Next to it is a parting tool, the blade being sectioned so that grinding on the front only is necessary. Boring bars which employ tool bits are seen in Fig. 193.

There are many other special lathe devices, but those dealt with cover requirements for the normal run of work.

In some cases it is necessary to devise special chucks and holding devices, and with very small work it may be necessary to cement the part (by means of shellac) to a plate held in the chuck. The latter would crush or distort very small or thin work.

WATERPROOFING DRAWINGS

Special solutions are available for waterproofing drawings. One method is to soak two pieces of suitable cloth in melted wax and lay the prints between them. Iron with a hot flat-iron.

FIXING PENCIL DRAWINGS

Pencil drawings may be protected from smudging or becoming blurred by a thin coating of methylated spirit in which a small quantity of resin has been dissolved. The varnish may be applied with a brush, but a better way is to blow it on with a spray, which may be obtained at any chemist's. A wash of milk over the drawing will also serve to fix it.

LATHE CENTRES

There are many forms of lathe centres for various kinds of work and some notes on the types of these and their special uses may be of interest. The general type is shown in Fig. 194. Some points about this simple device may be useful. The standard cone has a taper of 1 in 20, which is a Morse standard, so that, in the case of a lathe mandrel having been inadvertently bored into (in doing face-plate work) a Morse standard reamer may be used in a Morse socket held in the barrel of the tailstock and fed into the mandrel very carefully with plenty of lubricant, and any damage reduced.

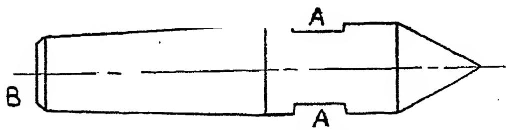


Fig. 194.—Usual type of lathe centre.

Similarly, when a tailstock barrel taper has been damaged (a very unusual occurrence), a Morse taper reamer carried in the taper of the mandrel may be used to clear it. Since the taper is such that the reamer is likely to bind, it should be traversed up very carefully, cutting very finely, and for this reason it is best to pull the mandrel round by the belt and not to use power for the operation.

Hardened Tailstock.—The tailstock centre must be hardened. But it is not necessary to harden the headstock centre unless there is available means for grinding it true in position after hardening. There is always a chance of a centre warping when hardening and tempering it. This would be fatal to accurate work in the case of the headstock centre, and since it has no rotation upon it—does not act as a bearing as does the tailstock centre—it is common practice to leave the headstock centre soft—or as soft as the unannealed cast steel leaves it after turning. In this case no grinding becomes requisite.

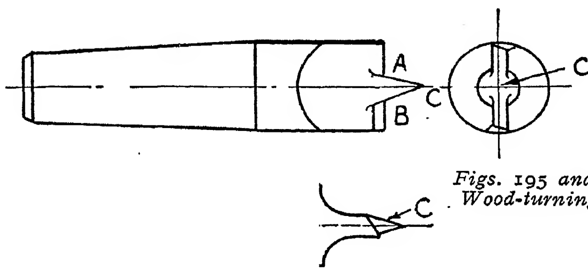
To enable the centre to be readily withdrawn it should have a couple of flats filed or milled upon it as shown at *A A* in Fig. 194, and these should be at such distances apart from each other as to fit a standard spanner. Both headstock and tailstock centres should be fashioned to suit the same rigid spanner.

The Top Slide.—In setting the top slide to cut the requisite taper, mount a Morse taper-shank drill or reamer in the three-jaw chuck, with the taper end projecting, and use this as a guide

for setting over the top slide. Note that Morse tapers over No. 3 size (that is ·778 in. at the small end) have a taper of or exceeding ·5191 per in. so that it is best to use the No. 1 taper which is dead ·5 in. or 1 in 20, the standard for lathe centre tapers.

But the taper shank must run true before setting the top slide to it. The end of the taper should be chamfered as shown at *B*. This is to ensure against the end of the shank of the centre damaging the taper bore.

In the case of hardwood turning, such as is often necessary in pattern making, the headstock centre has to drive the work



Figs. 195 *and* 196.—*Wood-turning centre.*

and is formed as shown in Figs. 195 and 196. The centre and pip is turned circular first and then the chisel edges *A* and *B* (Fig. 195) are filed along and the back clearance filed. These edges give the drive while the centre pip *C* centres the work.

The tailstock centre for woodwork is shown in side and end view in Fig. 195. The centre pip *A* locates the work and the ring *B* prevents the work being pushed off the centre—dotted lines show the shape of the centre pip and steady ring *B*.

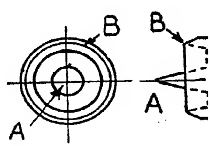


Fig. 197.—*A tailstock centre for woodwork.*

In some cases a running centre is advisable. This is shown in Fig. 198. The centre is hollow and carries a spindle *A* which fits it along the parallel part from *X* to *Y*. The bore is then flared out and ends in a ball race *B* and the spindle *A* is formed with a corresponding ball race at *C*: this takes the thrust and the spindle is held up by a washer and two locknuts *D* at the

tail end. An oil hole should be bored at E so that the parallel part can be lubricated.

Such a ball centre at the tailstock end ensures against damage

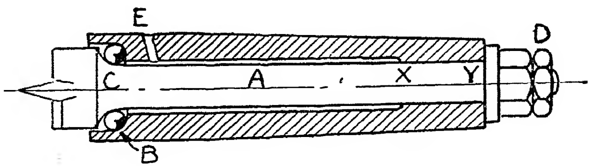


Fig. 198.—*A running centre.*

to the work or the chance of it being worn by the rotation and becoming loose between centres.

Running Centre.—A simpler type of running centre is shown at Fig. 199. Here the body is of phosphor bronze and the running

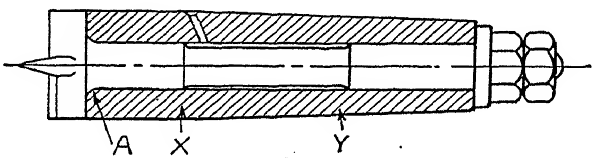


Fig. 199.—*Another type of running centre.*

centre is reduced from X to Y to form an oil chamber. A hole, as shown, is drilled for introduction of the lubricant and the shoulder at A should be nicely rounded as shown.

In metalwork it is sometimes necessary to centre a piece in which it is not possible to have a centre hole. In such cases a female centre is used as shown in Fig. 200. This may be for either the headstock mandrel or the tailstock barrel or both. It should be hardened inside the cone and, to avoid risk of warping and so going out of truth, it is a good plan to make these female centres of Bessemer steel and case harden the internal cone with "Kasenit," giving it a good soaking at a full yellow red heat with the Kasenit powder melted upon it and then quenched in salt water.

In using such a centre the work should, if possible, be provided with a fair width of chamfer at X to exactly the same angle as the internal taper in the centre, which could conveniently be an included angle of 90 degrees as shown. In the case of the head-

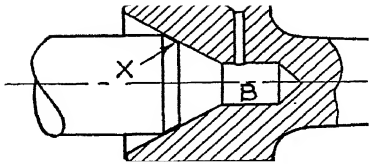
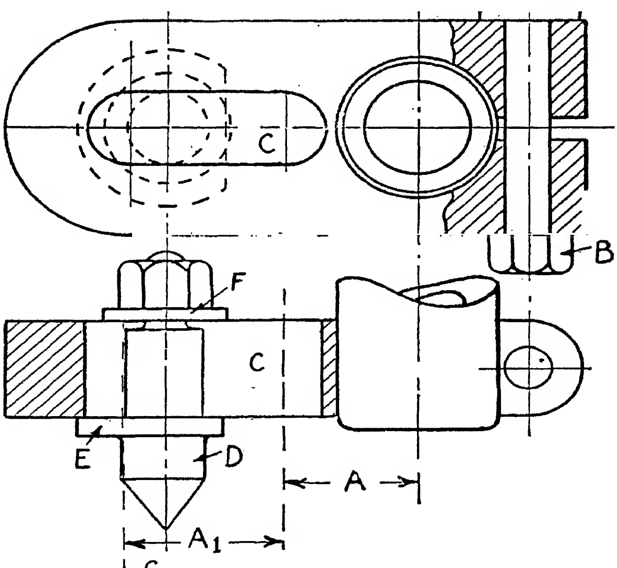


Fig. 200.—*A female centre.*



Figs. 201 *and* 202.—*For turning long tapers when a lathe is not provided with a set-over tailstock this set-over centre should be used.*

stock centre of this kind it is not necessary to case harden it. Provision should be made in the case of the tailstock centre to apply oil while the work is between centres, since the bearing surface is large. An oil hole is shown at *A* ; it should lead into the clearance space *B* and not to the surface of the cone, in which case it might get obstructed by the work and sufficient lubricant could not be introduced.

Long Tapers.—In turning long tapers in a lathe not provided with a set-over tailstock the arrangement shown in Figs. 201 and 202 will be found useful. To prevent its turning round under the cut it is clamped to the tailstock barrel and can be used for tapers in either direction—large at the tailstock end or large at the headstock end—by simply turning it half round. It cannot deal with tapers of sc small a rate as would entail the end of the

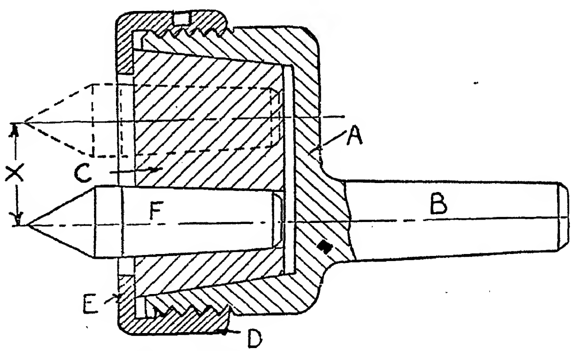


Fig. 203.—*Another form of adjustable centre.*

work being set nearer the trial centre than indicated at *A*. Its range is the distance *A*1. It is made from a piece of bar cast steel bored to fit the end of the barrel and counterbored and slotted to take the clamping bolt *B*. The slot at *G* takes the waist of the centre *D*, which has a shoulder at E and a clamping nut and washer at *F*. The slot *G* can be bored, chipped and filed out and no great accuracy is required nor fine finish.

In Fig. 203 is shown a type of adjustable centre which will give any degree of set-off from true alignment within the amount shown at *X*. The body *A* is in one piece with the taper centre shank *B* and is recessed with a taper bore in which fits the taper block *C*. This, when in position with the internal taper of the body *A*, projects an eighth of an inch beyond the face of *A* and

an internally screwed ring *D* with an internal front flange *E* is screwed along threads on the body *A* and forces the block *D* tightly into the body. The block *D* is bored to take the lathe centre *F* and in the position shown this centre is in line with the taper centre shank *B* which fits in the tailstock barrel. It is shown in plan.

Set-off.—By rotating the block *C* in the body *A* the lathe centre *F* can be put at any distance within the limits of the distance *X* between the dotted lines, because the body *A* is eccentric to the axis of the centre shank *B* within the limit of the distance *X*; therefore we can get any amount of set-off of the centre relative to the axis of the tailstock. The body *A* is located relative to the tailstock barrel so that whatever the eccentricity of the centre *F* it is at the correct height from the lathe bed.

The taper shank *B* should be a very good fit in the tailstock barrel and should be longer than usual. It should be tapped up firmly, when its position has been ascertained, with a mallet or copper hammer; otherwise the stress of the tool against the work may tend to turn it and upset the line of centre decided on for the rate of taper being turned. This applies also to the screwed ring *D*, which should be tightened, once the correct eccentric adjustment has been made, by a pin spanner in holes in the periphery of the ring, one of the holes being indicated at *G* in the drawing.

Cut-away Centres.—It is possible to obtain half- or cut-away centres, which permit a facing cut to be taken right across the end of a shaft. The flat of a centre of this type must be set vertically.

Hollow Centres.—These are used when the end of the work is conical or pivoted. A clearance is provided at the bottom of the conical recess in the centre.

Other special centres are devised according to the shape of the work.

BLACKENING BRASS

Add to a solution of copper sulphate (bluestone) a strong solution of washing soda; allow this to settle, pour off the liquid, and add a quantity of water equal to the liquid poured off; then allow to settle again. Next pour off as completely as possible, take the green sediment with four times its volume of water, heat to 140° F., and add ammonia gradually until the articles immersed in it assume the desired colour.

LATHE TOOL-BITS

The advantages that are to be had in employing tools of the holder type are many. In the first place the "tool-bits" for use in these holders are of "high-speed" steel and are supplied in a hardened condition throughout their entire length. By reason of the fact that the squared hole in the holder is drifted through at an angle in relation to the base, top rake is automatically given to the tool-bits when secured in position. Further to this, the bits are cut off at each end to an acute angle which at first sight seems excessive, but when in the holder gives approximately the correct amount of front clearance to the tool.

Different makes of tool-bits vary as to the shape of the ends. Some of them are cut in the manner described square with the normal top face of the tool, others cut them diagonally so as to provide something approaching both front and back clearance, and in several instances the ends are roughed out to shape. Thus it will be seen that the steel comprising the tool can be used until too short for the holding screw to grip it. A different-shaped tool may be ground at either end, and the hardness of the steel remains the same throughout the life of the tool. With initial grinding and subsequent resharpenings it is only necessary to remove very little actual material, and the length of the tool shank always remains constant. Also there is no comparison between the amount of work that can be done between grindings when using high-speed steel tools as against those of ordinary carbon tool-steel. The particular type of holders referred to range from shank sizes of $\frac{1}{2}$ in. $\times$ $\frac{5}{16}$ in. suitable for lathes using normal tools $\frac{1}{2}$ in. in thickness. The bits or cutters for use in this size are $\frac{3}{16}$ in. square. Other sizes correspondingly deeper in section take tools increasing in the size of the square by $\frac{1}{16}$ in. in proportion to the size of the holder shank.

These holders are made in types in which the cutter lies straight or offset in a right- or left-hand direction in relation to the shank, while holders are to be had in which the cutter can swivel on the shank; the line of the top of the cutter is in this type parallel with the top of the shank.

General Work.—For general work the straight type is as good as any; provision can be made by grinding the cutting face of the tool at an angle to the centre line of the shank, so as to allow the shank to swivel in the desired direction for clearance purposes, and yet maintain the cutting face square with the work, as for instance in the manner of a right- or left-hand knife tool.

As regards the actual grinding of the tools, the side and front clearances should be ground on the side of the wheel, as hollow-grinding on these faces is undesirable. For general work if these clearances are made within a degree either way of 9 degrees they will be found satisfactory. The side rake on the top of the tool can be from 15 to 25 degrees sloping away from the cutting edges. This face can be hollow ground. For the sake of durability the side rake is made less for harder materials. Brass tools may to advantage be made with increased side and front clearances, but the top and side rake must be absent if " digging in " is to be avoided. In other words, a flat-topped tool is essential. To avoid alteration in the shape of tools from time to time, a half-dozen tools can be ground up at both ends to cover requirements.

Facing in the Chuck.—In Fig. 204 a piece of mild steel is being faced. Set the material fairly close in to the jaws of the chuck. The tool-bit is held in the holder so that a short length is projecting. Clamp the tool holder at an angle of about 45 degrees with the work and so that the highest point of the tool is approximately central. Move the tool away from the centre and feed into the work lightly by moving the top slide feed back to the centre when the tool should finish exactly central, that is, leaving no projection. Proceed then to face outwards as in Fig. 204;

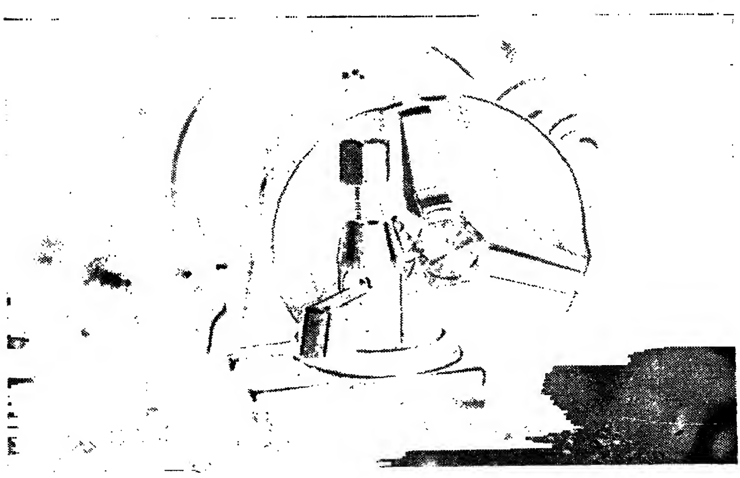


Fig. 204.—Facing up a piece of mild steel.

note that the face is being left flat from the centre. If the tool is too low a pip will be left on the work in the centre (see Fig. 205); whereas if too high it will be impossible to reach the centre with the tool.

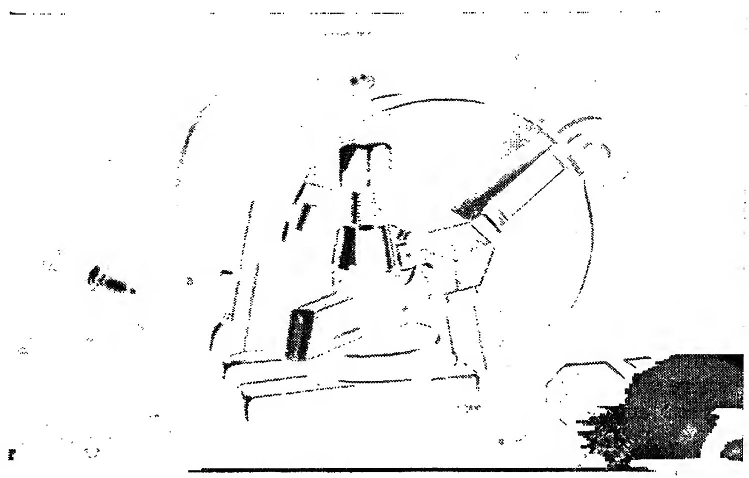


Fig. 205.—If the tool is too low a pip will be left on the work in the centre.

The result of having the tool holder too flat in relation to the facing cut is seen in Fig. 206. This is caused by the side clearance rubbing against the metal being removed and pushing the cutter out of the way, leaving a hollow in the centre. This would not happen if the feeding was done in an opposite direction, from outside to centre, but the tendency is then, under a heavy cut, for the nose of the tool to cut all round, forming a groove in the material as it feeds in. The direction of thrust is such that it tends to swivel the tool and increase the depth of the facing cut, and may result in scrapped work. The tool used in this instance is a right-hand turning tool which feeds towards the left, normally producing a right-hand shoulder. With a rocker bar or "Yankee" type tool post, as shown, the tool setting is a simple matter. With a plate or box type tool post requiring packing beneath the tool to adjust the height, fine adjustment can be made by sliding the tool-bit in or out of the holder slightly.

With regard to the tool shape the profile is such that the left-

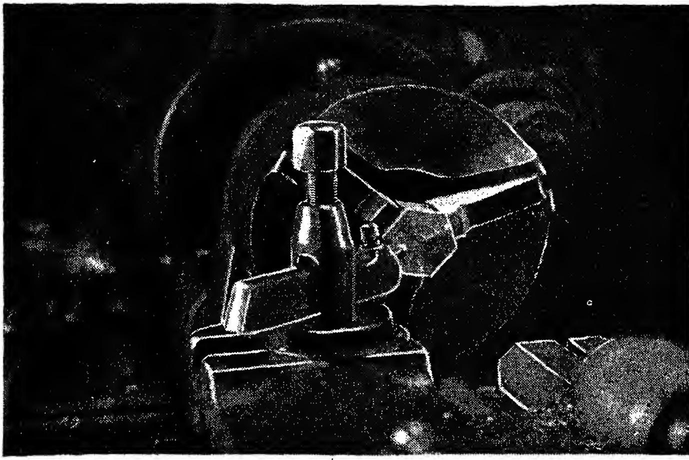


Fig. 206.—Showing the tool holder adjusted too flat in relation to the facing cut.

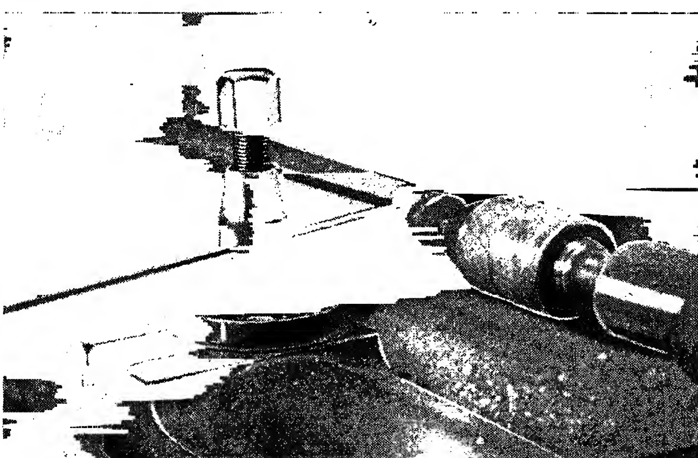


Fig. 207.—A method of centring bright bar so that it will run truly.

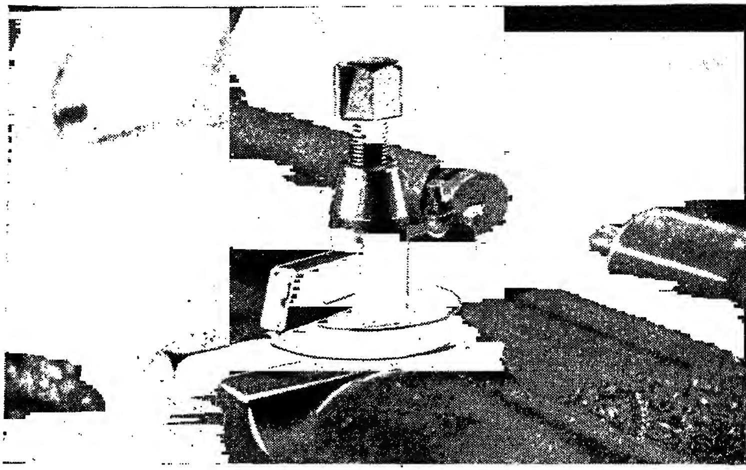


Fig. 208.—Setting the tool for centre height.

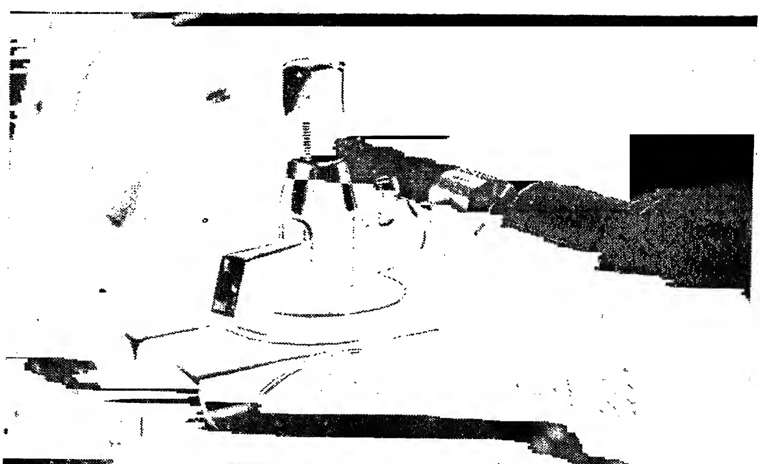


Fig. 209.—Showing a cut being taken which is cleaning up the bar with a reduction of only ·004 in. in diameter.

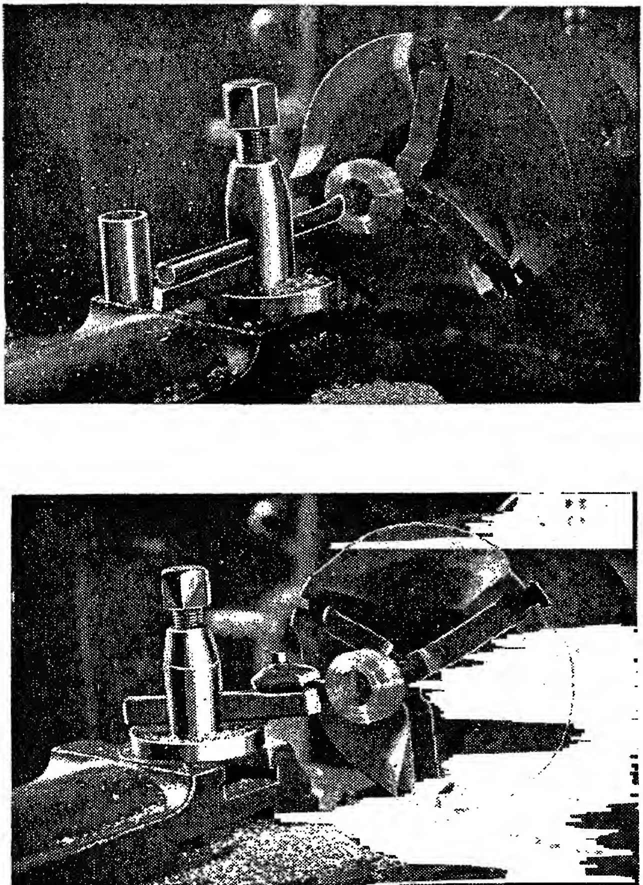


Fig. 209A.—*These two illustrations show the application of the tool to facing operations.*

hand or cutting face is parallel with the shank, the front being ground to form an angle of 60 degrees to 70 degrees with the opposite face and the point given a small radius. Previous remarks as to rake angles apply in this instance. Finish will be governed by the rate of feed and size of radius at the point. Stone the point of the tool and take a fine finishing cut, using a slow feed with soapy water as a lubricant to produce a mirror-like finish in steel.

The aim is to secure the necessary degree of finish from the tool direct, as this is more accurate than polishing.

Centring.—Before work can be performed between the centres, it is, of course, necessary to centre up the ends of the work. This is a drilling operation. A small hole is drilled central in the end of the bar and countersunk at an included angle of 60 degrees to match the lathe centre. Unless the centre hole is accurate as regards angle and the small hole continues deeper than the countersink, the hole will wear or be otherwise unsatisfactory. For this reason a combination centre-drill is recommended.

A method of centring bright bar so that it will run truly is shown in Fig. 207. The bar is held in the chuck with a fair amount projecting. When the work is revolving it is pushed true and steadied by the Vee-ended bar held in the tool-post while centre drilling. After drilling both ends it is preferable to rough out the job in the chuck. Set the tool for centre height as in Fig. 208.

Steady the end of the bar with the back-centre, using oil to lubricate the point of the centre. The same tool as that described for facing can be used for "roughing out." By using the method of centring described, it is only necessary to leave a minimum amount above the maximum diameter of the finished job. As a proof of this, the cut being taken in Fig. 209 is cleaning up the bar, with a reduction of only ·004 in. in diameter.

CELLULOID CEMENT

Dissolve fine scraps of celluloid in amyl acetate. The parts to be joined should be scraped clean and coated with amyl acetate and a film of the cement applied.

METAL TO EXPAND ON COOLING

This may be made from 9 parts by weight of lead, 2 parts by weight of antimony, and 1 part by weight of bismuth.

GRINDING OPERATIONS

The demands of certain classes of work are such that a high degree of accuracy plus good surface finish is called for. Satisfactory work may be produced, providing that a fair degree of skill is employed, by the use of ordinary turning methods. Where the part or parts are subsequently heat treated, the care bestowed in obtaining accuracy and finish frequently results in wasted effort. It is true that parts made from mild steel may, with careful handling, be lightly case hardened and polished without any appreciable deterioration in the surface condition (a point also applying to direct hardening steel, providing that the hardening temperature is a relatively low one). The fact remains, however, that the distortion, even if only slight, resulting from heating and quenching is sufficient to render the part unserviceable. The nature of this distortion would depend upon the character of the part. Thus an object in the form of a bush may shrink or become oval, while one in the nature of a spindle of appreciable length will tend to warp.

Grinding forms the most reliable and effective method to employ as a finishing process for parts which need to be hardened. As may be gathered, these remarks are intended to apply mainly to cylindrical work. Grinding of this nature is normally carried out on a machine specially designed for the purpose, but really good work can be produced by adapting a lathe to perform the operation.

A certain amount of additional equipment in the form of a grinding attachment will be necessary; this aspect of the process will be dealt with in a later section. However, in this direction two important points must be stressed before good results can obtain, namely, the attachment must be rigidly mounted on the lathe and the grinding-wheel spindle needs to be a good fit in its bearings.

Grinding Wheels.—Apart from the attachment, one of the important factors bearing on the quality of the work produced, is the question of proper grinding-wheel selection. It is not sufficient merely to have a grinding wheel of requisite diameter, width, and bore to suit the attachment, as the wheel must conform to requirements in other respects as well. The importance of these requirements will be more readily understood when it is realised that grinding is actually a cutting process in the same way that turning is, the material being removed in the form of microscopic shavings.

A grinding wheel is composed of abrasive particles held together by a bond, these particles, sticking out from the face of the wheel, providing thousands of separate cutting edges. Thus it will be seen that the size of the particles will have a bearing on the finish obtained.

Wheels, manufactured by one of several processes, are termed vitrified, silicate, rubber, or elastic. The processes differ, chiefly as regards the method of bonding the abrasive particles together. Each type of wheel has its particular sphere of usefulness. A greater number of wheels by far are made by the first process than any other, and those so made are readily distinguishable by their colour, which is a warm shade of brown. This type of wheel is most suitable for the general requirements.

Grade and Grain.—The term "hardness" as applied to grinding wheels refers to the manner in which the abrasive particles are held together. In use, the cutting particles should break away from the face of the wheel in contact with the work when they become too dull to cut, and so expose, as it were, a fresh set of cutting edges.

Different classes of work and conditions require wheels of different grades, so that whereas one that is too soft for a particular job will wear away rapidly, one that is too hard will soon glaze up. The usual method of designation of grade is by a letter of the alphabet. As already mentioned, the work in which the mechanic will be interested is that which is hardened, and the most suitable grade of wheels for such work will lie in the soft range represented by letters I, J, K, and L. The grain of the abrasive has a definite relation to the size of the particles, i.e. No. 46 grain has been passed through a sieve with a mesh having that number of holes per linear inch; thus the higher the number, the finer the grain of the wheel. For hardened-steel parts the grain of suitable wheels will lie between Nos. 46 and 60. Mention should here be made of the fact that elastic wheels are usually marked with a numeral to indicate grade, Nos. 1, 1½, 2, and 2½ representing the soft range. Such wheels are unsuited to general grinding, but a narrow wheel of this kind may be employed in cases where an ordinary wheel would otherwise require dressing extremely thin.

There is one other point, and that is in regard to the kind of abrasive, which has a marked effect on the performance of the wheel. Aluminium oxide is probably the best abrasive for the work under discussion, and wheels so composed are sold under the trade names of alumdum, aloxite. etc.

Conditions affecting Grinding Wheels.—It is impossible to advise regarding wheel selection unless the actual conditions in which the grinding is to be carried out are known. The surface speed of the wheel and work must be taken into consideration and also the question of whether the continuity of the grinding will be intermittently interrupted by anything in the nature of keyways or splines. A grinding wheel should be run at a speed in revolutions or feet per minute very closely approximate to that stated on the tag attached to the wheel when purchased. The effect of running under speed is the same as if the wheel were of a softer grade than it actually is, and it may therefore wear away quickly in use. An excessive speed, on the other hand, has the reverse effect in regard to the grade, and is a practice that should never be indulged in, having consideration for safety. Where the work is relieved by keyways, etc., it is advisable to use a slightly harder wheel than that used for similar plain jobs, owing to the abrading action of the sharp corners.

Mounting Grinding Wheels.—Grinding wheels, with the exception of those intended for small internal work and those of the "plastic" variety, are supplied with a lead-bushed central hole (Fig. 210), which fits the grinding spindle. The wheel should

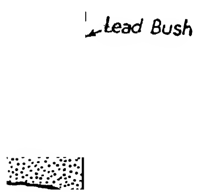


Fig. 210.—A grinding wheel with a lead-bushed central hole.

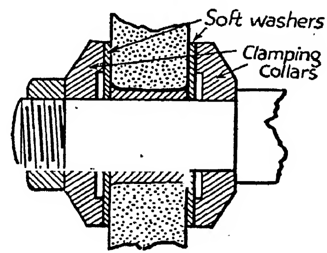


Fig. 211.—The method of clamping the wheel on the spindle between two washers.

be clamped on to the spindle between large collars recessed away in the centre (see Fig. 211). The inner collar nearest to the shoulder on the spindle is preferably made a tight fit, or, better still, fitted over a small peg to act as a key. A thick paper washer (made from something in the nature of heavy blotting-paper) should be interposed between each side of the wheel and the collars before tightening the nut. Most wheels are provided with suitable paper washers, but this point must not be neglected or

the wheel may crack under the strain of tightening. Washers made from thin rubber insertion are more effective and will give considerably greater service. On no account must ordinary small engineers' washers (Fig. 212) be used to clamp the wheel between, as these will provide insufficient drive and, further, will cause the wheel to move on the lead bush. It may happen that a grinding wheel (or wheels) can be picked up which are suitable except for the fact that the centre hole is too small for the

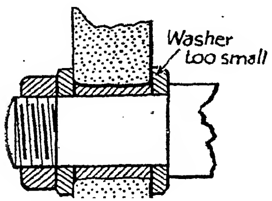


Fig. 212.—Small engineers' washers should not be used.

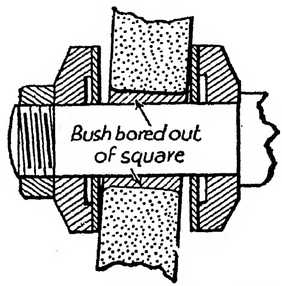


Fig. 213.—A badly set wheel that may lead to breakage.

spindle. When such are to hand, care should be exercised in opening out the lead bush. This is best accomplished by setting up the wheel true in the lathe, and boring out with a boring tool. It is an easy matter to open out by hand, but not so as to ensure that the hole is at right angles to the side. This may lead to the result seen in Fig. 213, which, if not noticed, may lead to breakage.

Wheel Truing.—Before any grinding can be attempted the face of the grinding wheel needs to be dressed true and flat. A wheel surface good enough for cylindrical grinding will not be

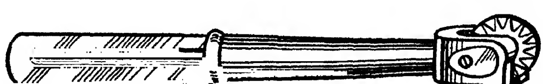


Fig. 214.—A " huntingdon " type of dresser.

obtained by the use of a " huntingdon " type of dresser, Fig. 214, or one of the type shown in Fig. 216. These types are intended for hand use on tool or general grinding heads. An ideal tool to use is a diamond dresser (Fig. 215). This may be used as a hand

dresser or mounted as afterwards described for the present purpose. Such a dresser or small diamond mounted in a small shouldered stud will cost about 25*s*. A substitute not quite as effective in use is a "diamcarbo" dresser shown in Fig. 217. This consists of a steel tube filled with an abrasive mixture similar to carborundum. This wears away in use and the tube acting as a

Diamond

Fig. 215.—*An ideal tool is the diamond dresser shown.*

support is ground away at the same time. Possibly the best method of mounting the truer is to make a substantial centred shaft having a hole direct through the centre and fitted with a set screw to take the shank of the truer after the manner of a boring bar. This is fitted with a carrier and locked between the centres, with the tail of the carrier resting on the driving pin to stop the shaft from rotating. The point of the dresser is set towards the wheel and central with it, the truing being effected by driving the

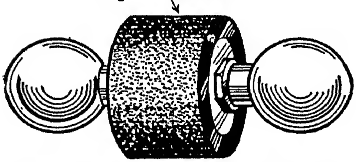


Fig. 216.—*This type of dresser is suitable for hand use only.*

Steel tube containing abrasive

Fig. 217.—*A substitute for a diamond dresser.*

grinding wheel and bringing it in contact with the truer, traversing the wheel backwards and forwards with the saddle. Where the face of a shoulder has also to be ground the side of the wheel will need dressing appropriately. To accomplish this the dresser will need mounting on the catchplate in a manner similar to that described, or a flange to serve the same purpose fitted to the shaft, the dressing being carried out by feeding the wheel to the dresser by saddle movement and working the cross slide.

Dead Centres.—Prior to grinding work between the centres, see that the points of both centres are in good condition and that the headstock centre runs truly when the spindle is revolved. Greater accuracy and better grinding will be attained by working

on "dead centres." This is accomplished by making a boss to screw on the nose of the lathe, on which a pulley secured by a screwed ring runs (as in Fig. 218). A driving pin is fitted to the face of the pulley and drives the work via a carrier.

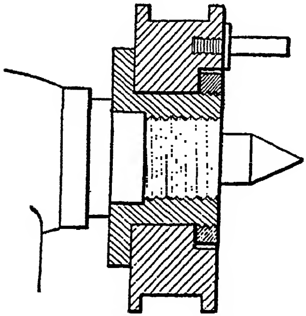


Fig. 218.—Greater accuracy and better grinding will be obtained by working on "dead centre."

Preparation of Work for Grinding.—Work which is to be finished on centres needs to be accurately centred with a combination centre drill as deeply as possible to provide good bearings. Changes in diameter should, where the difference is substantial, have an undercut between them; and where the face of the shoulder requires grinding, the undercut should be made in the corner, as seen in Fig. 219. This undercutting is essential where the diameter being ground must remain constant to a point close up to the shoulder and also to preserve a sharp corner on the wheel. Hardened mild-steel parts will need to be deeply case hardened. Open-hearth treatment will prove unsatisfactory, as the depth of case so obtained will be removed by grinding.

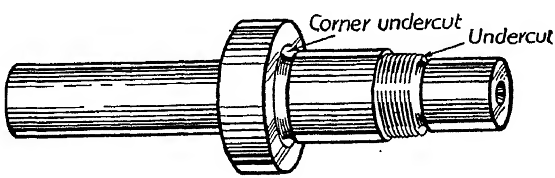


Fig. 219.—The method of undercutting where the face of a shoulder requires grinding.

As a general rule the following allowances for grinding will be ample, providing that the finish of the turning is reasonably smooth. Outside diameters plus 0·010–0·015 in., faces of shoulders plus 0·002–0·004 in., and minus 0·005–0·008 in. in internal diameters.

It is difficult to lay down any hard-and-fast rules as to work speed, etc., as many factors have to be taken into account. A work speed of between 20 and 50 surface feet per minute will

probably give best results. Too slow a speed may cause burning of the work locally, while one that is too high is likely to cause chatter. Light cuts should be taken and the wheel traversed fairly quickly, far in excess of the feed likely to result from the sliding motion. On this account the saddle is best wound along by hand, as it can thus be better controlled.

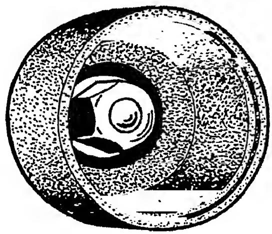


Fig. 220.—*A cup grinding wheel.*

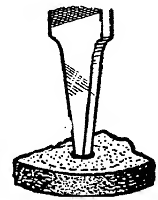


Fig. 221.- *Boring a hole in a broken wheel with the tang of a file.*

With the lathe running normally the wheel, if in front of the work, will need to run upwards. This should be avoided, as the sparks will fly upwards and may be dangerous to the eyes. Where a dead-centre attachment is made the direction of rotation of the work can be reversed by a crossed driving belt, otherwise unless the grinding wheel can operate behind the work a crossed belt on to the cone pulley becomes imperative. For internal work the direction of rotation must be reversed—either the workpiece or the grindstone; in other words, for external grinding workpiece and grindstone rotate in the same direction, but for internal grinding workpiece and grindstone rotate in opposite directions.

Small internal grinding wheels can easily be made from portions of broken wheels about $\frac{1}{4}$-in. thickness by boring a hole with the tang of a file and rough grinding to shape, finishing to size on outside with the wheel truer (see Fig. 221).

Some surface grinding can be carried out by mounting the work on the faceplate and using a cup-shaped grinding wheel. For flat work to result, the face or edge of the cup needs to lie parallel with

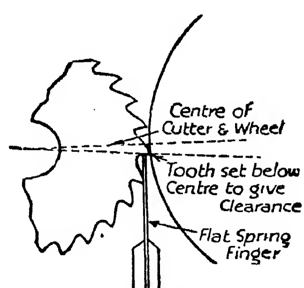


Fig. 222.—*Details of the spring tooth-rest.*

the faceplate. Where the width of the work will permit it will not be necessary to rotate the work, but owing to the power consumed and heat generated, the surface of the wheel may require reducing in width by dressing away as in Fig. 220.

Cutters and reamers can easily be sharpened between the centres or on a mandrel providing that a spring tooth-rest is fitted to support the teeth and permit indexing, as in Fig. 222.

Testing Iron and Steel on Grindstone.—A skilled mechanic can determine the type of a piece of steel by " sparking " on a dry grindstone. Wrought iron will yield a longish spark of light straw colour, and mild steel a longish light straw spark with tails similar to arrow points. With tool steel the sparks are white and shorter, but have a greater number of arrow points, while high-carbon steel yields a cluster of fine white sparks.

Manganese-iron and steel yield a few white sparks a fair distance apart, high-speed steel very minute chrome yellow sparks, mushet steel dark red sparks, and magnet or tungsten steel orange sparks.

It is a good plan to test a number of pieces of different grades of steel in this way ; when in doubt as to the nature of the steel, test it against a piece of known grade.

Diamonds for Truing.—It is important to select a diamond of a weight according to the size of the wheel, and the following table will form a useful guide.

HARD WHEELS

Diameter.	*Width of Face.*	*Diamond Weight.*
Up to 12 in.	1 in.	1 carat
12 in. to 18 in.	1 in. to 1½ in.	1½ to 2 carat
18 in. to 24 in.	2 in. to 4 in.	3 to 5 carat

SOFT WHEELS

Up to 6 in.	1 in.	¾ carat
6 in. to 12 in.	1 in.	1 carat
12 in. to 18 in.	1 in. to 1½ in.	1¼ to 1½ carat
18 in. to 24 in.	2 in. to 4 in.	2 to 4 carat

Diamonds should be fixed in their holders by brazing. The cheaper type of diamond, known as *bort,* should be purchased.

Speed of Grindstone.—To avoid glazing of the stone and the necessity for frequent truing and dressing with the diamond, the wheel must be driven at the correct speed, and it must also be of the right grade and grain according to the degree of hardness of the material to be ground. The following will be found a useful guide:

Tool grindstone	400 to 900 ft. per min.
Finishing wheel (wet) . . .	4,000 to 5,000 ft. per min.
Finishing wheel (dry) . . .	3,500 to 4,500 ft. per min.
Polishing by emery and oil . .	3,500 to 4,500 ft. per min.

In all cases the makers recommend suitable speeds.

Balancing a Grinding Wheel.—In order to avoid chatter marks on the work, and to avoid risk of the wheel cracking and "flying," it should be poised or balanced by countersinking the lead bushing, or adding extra lead to the boss.

Testing for Cracks.—Suspend the wheel on the finger from the bore and tap it. If it is not cracked it will yield a clear ring. On no account use a cracked wheel; a guard *must* be fitted over grinding wheels.

Lubricant for Grinding Wheels.—Where the work must be ground wet, do not use water, except grinders used for grinding lathe and other tools.

For finish grinders use soda water. This dries white, and oil should therefore be rubbed on the work after grinding to avoid soda stains.

Form Grinding.—By suitably shaping the face of a wheel with a diamond, using a metal template to bring the edge of the wheel to the desired shape, it is possible to grind forms and shapes, provided, of course, that such are not undercut. Where a lot of material has to be removed, it is best to have one wheel for roughing and one for finishing.

It must be remembered that as the work heats up it will expand, so when accuracy of size is important, the finishing cut should be very light—not more than half a thousandth of an inch—and this cut should not be made until the work has cooled down and its size checked to determine the exact amount to be taken off on the finishing cut.

GRINDING IN THE LATHE

While a centre lathe is primarily intended to be a machine for performing operations that are strictly regarded as turning, its general design is such that it may be easily adapted for use in other directions outside of this sphere.

The operation that is most akin to turning is cylindrical grinding, and as a general rule all turned work that is subsequently hardened should be finally ground. Other forms of grinding, such as cutter and surface, can also be conveniently carried out on the lathe.

Frequently, the lack of facilities for carrying out such opera-

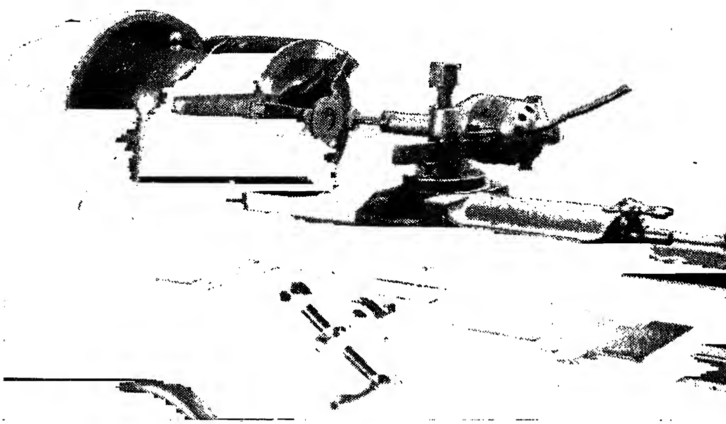


Fig. 223.—A small internal grinding attachment shown fitted to the lathe.

tions is the cause of a finished job falling short of perfection. Therefore it is proposed to deal with the adaptation of the lathe for grinding processes.

Extra Equipment Necessary.—The extra equipment necessary to complete the conversion is really very little, and as to the question of outlay, the reader who is so disposed may make the attachments for a fraction more than the bare cost of the material involved. Briefly, what is required is a driven spindle carrying a grinding wheel mounted on the tool platform in place of the usual turning tool. As may be imagined, a motor-driven unit

specially made for the purpose provides by far the simplest solution to the problem. Such electrically driven self-contained "tool-post" grinders are to be had in great variety. These may be suitable for external or internal work, or a combination appropriate for both classes. The power of the motors fitted are usually of the order of $\frac{1}{6}$-h.p., and therefore may be plugged into the lighting circuit. A small internal grinding attachment of this description is seen fitted to the lathe in Fig. 223. The wheel spindle is removable by unscrewing the knurled collar on the necked portion of the casing, so that other spindles of different diameter or length may be substituted as required. A diagram of a combination attachment is shown in Fig. 224. Here the external wheel is driven at armature speed, and the internal spindle driven with an endless belt by a pulley at the opposite end of the armature spindle. The means provided for mounting in the tool post is so arranged that the attachment is simply clamped in position with the spindle required nearest to the nose of the lathe. When the internal spindle is not in use, the belt should be slipped off, so that the full power of the motor may be utilised to drive the large grinding wheel.

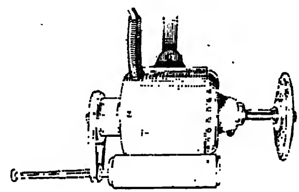


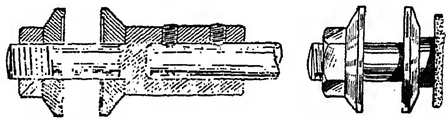
Fig. 224. — A combination grinding attachment for the lathe.

Converting an Existing Motor.—An existing motor in the region of a $\frac{1}{4}$ h.p. suitable for the mains current available may be converted for use as a grinder, providing that the armature is mounted on substantial bearings. If the motor is a modern one, it will be fitted with ball bearings, which is an advantage; but precautions should as far as possible be taken to exclude the entry of grinding dust into the bearings and inside of the motor.

The question of mounting the motor must first be considered, and probably the simplest way of so doing will be by fixing the motor to a baseplate. On account of bringing the armature spindle down to centre height, it may be necessary to remove the top slide of the "compound," and mount the baseplate directly on to the cross slide in substitution. While this will provide a rigid fixing and enable good work to be produced between the centres, it will not permit of taper grinding being carried out on work held in the chuck. As, however, most jobs may be tackled, this objection is not a serious one.

Having decided on the method of fixing the motor, the next

step is to adapt the spindle to carry a grinding wheel. This can be done by making an adapter as shown in Fig. 225, or, where the diameter and length of spindle will permit, by altering the end as shown in Fig. 226. The first example affords the best method,



Figs. 225 and 226.—An adapter for carrying a grinding wheel. Right, how the end of the spindle is altered.

as the motor may still be used for other purposes. In making the adapter, it should first be roughed out and the hole bored to neatly fit the spindle. After fitting the grub screw or screws, the part is finished by turning on a true peg held by the screws. This should ensure that the extension runs perfectly true when in position. The internal grinding attachment may be fitted at the front of the baseplate (so that it can be detached when not being used), and driven by a belt from a pulley fitted in place of the grinding wheel, or with a friction wheel in direct contact with a pulley so fitted.

Flexible-shaft Drive.—Where the lathe is a small one, the dimensions of even the smallest motor giving sufficient power will be too great to permit mounting in the manner stated, and in such cases an alternative method must then be adopted. A flexible-shaft drive affords perhaps a simple solution, as the actual grinding head can be got down to quite small proportions.

Where such a drive is contemplated, the actual flexible-shaft unit should, on account of the high speeds involved for internal grinding, be one that is fitted with ball races. A shaft unit of this description is illustrated in Fig. 227. The head, shown separately, is in this instance provided with a collet for gripping the shanks of small arbors carrying the appropriate wheels. It is better to avoid purchasing a head that is permanently fitted with a

Fig. 227.—Details of a flexible-shaft unit.

drill type of chuck, as this is not nearly good enough.

The head may, of course, be made on the lines of those shown later, in which case the shaft only needs to be considered, and there is no reason why, for light work, an old speedometer driving shaft and casing should not be pressed into service for the purpose (see Fig. 228). Where, however, one of the commercial types of flexible shaft units is to be used, it will be necessary to provide some means of holding the head portion in the tool holder. Alternative methods of so doing, and which will meet the requirements of most types of tool posts, are shown in Fig. 229. No actual dimensions can be given, as these

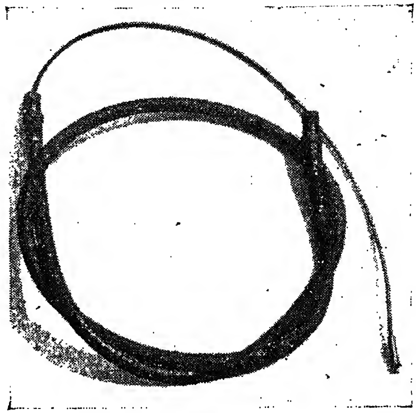


Fig. 228.—For light work, an old speedometer driving shaft may be used.

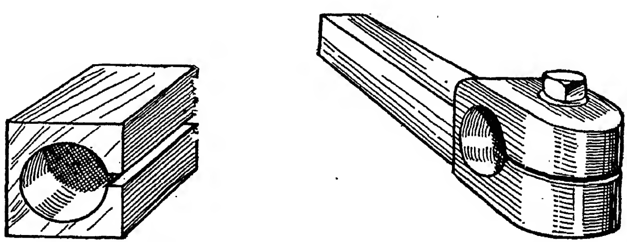


Fig. 229.—Alternative methods of holding the head portion of the flexible shaft in the tool holder.

will depend upon the diameter of the grinding head, height from tool platform to centre, etc. Other details are made clear in the sketches.

The flexible shaft may be motor-driven direct or via countershaft to give a range of speeds above that of the motor, and if fitted in this manner, will form a valuable addition to the workshop equipment, as its uses, apart from grinding, are numerous.

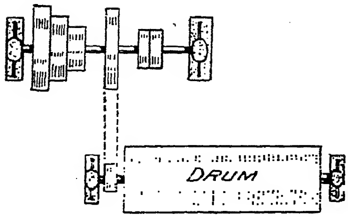


Fig. 230.—Belt driving a grinding head from a countershaft situated above the lathe.

Belt Driving from Countershaft.—Although a more or less self-contained electrically driven grinding head provides the most simple means of converting or adapting the lathe for grinding, the job can be accomplished by belt driving from a drum countershaft situated above the lathe, as shown diagrammatically in Fig. 230.

The driving drum should extend to more than the maximum distance that the lathe will take between the centres, taking care to arrange it in such a position that the down belt will not be unduly tightened or slackened when the cross slide is moved. Where the drum cannot be mounted in relation to a line through the lathe centres shown in Fig. 231, then a jockey pulley will

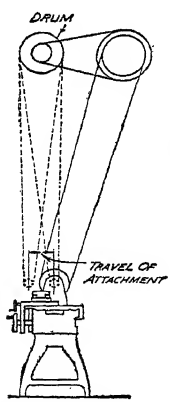


Fig. 231.—A jockey pulley fitted to compensate belt tension.

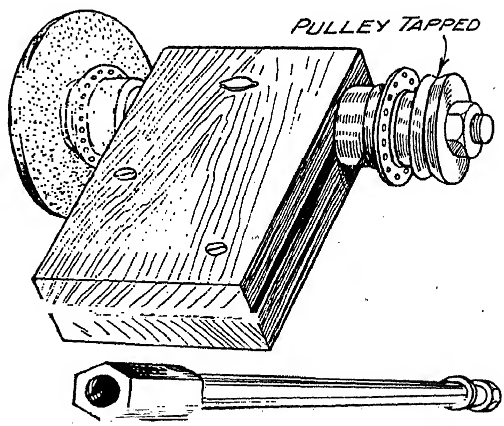


Fig. 232.—General arrangement of an improvised belt-driven grinding head.

need fitting to compensate belt tension; but this is a complication that is usually avoidable.

Belt-driven Grinding Heads.—The reader who is desirous of doing a little grinding on the lathe, and intends making the head himself, will naturally wish to achieve his aim with the

minimum of trouble. A ball-bearing head, which will produce creditable work of small proportions, may, with very little trouble, be contrived from a front hub of a bicycle. Very little actual work, if any, is needed in the way of alterations. A round belt will transmit all the power that is required, so that a Vee pulley is all that is wanted to take the drive. The flanges may be reduced in diameter to below the spoke holes for the sake of appearance, but this is not really necessary.

A general arrangement of the head and method of mounting is shown in Fig. 232, together with an adapter and shaft for internal work.

Belt-driven External-Internal Attachment.—A suitable design for making a belt-driven combination attachment is shown in Fig. 233. The external spindle is driven from a drum

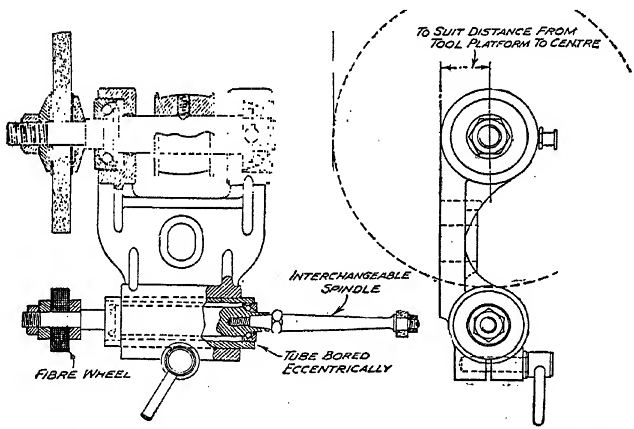


Fig. 233.—A suitable design for a belt-driven combination attachment.

situated above the lathe in the manner previously explained. The pattern making involved is of the most simple nature, one pattern being required for the bracket and one for the fric' pulley. As shown, the main spindle runs on ball bearings which can be on the lines indicated, or the design modified to incorporate standard combined journal and thrust ball races. Where this is

done, the inner rings of the races should be made to butt against shoulders turned on the spindle at either end, and screwed caps fitted to effect adjustment to the outer rings. If the centre of the caps are bored to clear the shaft and a groove provided in each one to contain a felt ring, a good dust-proof bearing will result.

The spindle may, of course, be mounted on plain bearings, but to do this properly, the bearings require to be adjustable and also an adjustable thrust-plate is an absolute necessity; so that, all things considered, the method shown or that suggested forms the easiest way to go about the job. To bring the internal attachment into use, the grinding wheel is removed and the aluminium pulley substituted. The bracket is then swung round to bring this pulley nearest to the tailstock. It should be noted that the round body of the internal attachment is slightly eccentric in relationship to the spindle. This enables the body to be rotated, and thus bring the friction wheel to bear against the face of the pulley with the right degree of pressure before finally clamping into position. No dimensions are given on the drawings, as the attachment will have to be made to individual requirements.

PATENTS—POSITION OF EMPLOYEE AND EMPLOYER

An employee who brings out an invention, even although he may have done so in his master's time, is entitled to apply for a patent. Further, he may be entitled to the benefit of the patent unless this would inflict an injustice on the master in view of the relations between them, such, for example, as a high salary and the confidential character of the employment, or a contract, express or implied, between them, in which case the patent may be obtained by the employee in trust for the employer. The Solicitor-General, in *re* Heald's Patent (1891, 8 P.O.R.430), said: "I am not aware of any authority which lays it down that the invention of a servant, even made in the employer's time, and with the use of the employer's materials and at the expense of the employer, thereby becomes the property of the employer, so as to prevent the person employed from taking out a patent for it."

If, however, the master suggests the main idea and the employee, in carrying it out, merely incorporates small improvements, the master's name must be in the Patent Application. If the master and servant have jointly produced the invention, both of their names must be in the Patent Application; and if the master is to receive the sole benefit of the patent, the patent can be granted solely to him.

THE DIVIDING HEAD

Milling machines and the headstocks of some lathes are fitted with a dividing head which enables the work, such as a gear blank, to be moved round a fraction of a turn so that the gear teeth, flutes, holes, etc., are equally spaced. There are the simple and the compound or differential dividing heads, but they all work on the principle of a worm and worm wheel. Fig. 234 shows the elements of the dividing head. It usually consists of a single-thread worm and a worm wheel having 40 teeth, or some multiple of it such as 80, 120, etc.

It is obvious that, in order to revolve the worm wheel and anything coupled to it one revolution, the worm would have to be turned a number of revolutions equal to the number of teeth in the worm wheel. This device alone would be insufficient to cope with the multifarious spacings necessary, and so attached to the worm is a dividing plate having a series of holes, which enables the worm to be turned the exact amount according to the divisions required in the work.

Thus, if 50 divisions are required round a gear blank, the worm would be rotated forty-fiftieths of a turn. A number of dividing plates are always provided with each dividing head, and each row of holes is applicable to a given range of submultiples. For example, if it is wished to divide a blank round into 48 spaces and the worm wheel has 40 teeth, for each space the worm must be turned five-sixths of a turn; thus, a circle of holes divisible by 6 would be selected, such as a circle of 24 holes, 36, 42, etc.

If a 24-hole circle is used, five-sixths of a turn would necessitate the index fingers being set to embrace five-sixths of 24 holes, which equals 20 holes, plus 1 hole in which the peg is placed, making 21 in all. These index fingers are friction tight, and after one cut has been made, they are swung round and the division continued.

The index peg on the handle which operates the worm is adjustable so that it can be made to embrace any particular circle. The holes in a set of index plates will accommodate all numbers up to 50 and every even number up to 100. Reducing this to a formula, we have:

$$m$$

where M equals the number of turns of the handle per division of the work, t equals the number of teeth in the worm wheel, and m the number of divisions required on the work.

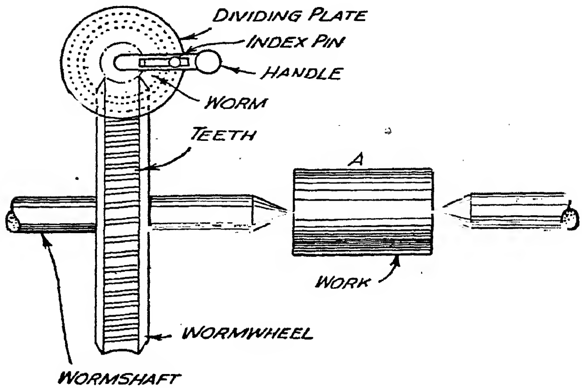


Fig. 234.—Elements of the dividing head.

GEARS

The tables at the back of this book give the formulæ for obtaining the various dimensions and proportions of involute spur gear teeth. It will be noted that the circular pitch is the distance measured round the pitch circle between any two adjacent teeth. The thickness of tooth is measured on the pitch circle and that part of the tooth above the pitch circle is known as the addendum, whilst that below the pitch circle is called the dedendum. A working clearance is given to the depth of the tooth, so that the top of the mating gear does not contact with the bottom of the gear. The addendum plus the dedendum and the clearance equal the whole depth. The working face or the pressure face of the gear tooth is known as the flank. The diametral pitch is found by dividing π (3·1416) by the circular pitch, and the product of circular pitch and diametral pitch must therefore equal π. Gears are usually cut by means of cutters of the Brown and Sharpe type, one cutter holding good for a certain range of gear teeth. The involute system usually adopted on spur gears has a pressure angle of $14\frac{1}{2}°$, whereas stub teeth have a pressure angle of $22\frac{1}{2}°$. It will be appreciated that the shapes of the teeth vary according to the number of teeth and the diameter of the blank, so that unless a special cutter is made for each gear, the shape of the teeth will only be approximate. They are thus usually cut about $\frac{1}{1000}$ in. thick, and run

into correct centre distances with glass powder and oil. Most gears nowadays are cut by the generating process, in which a

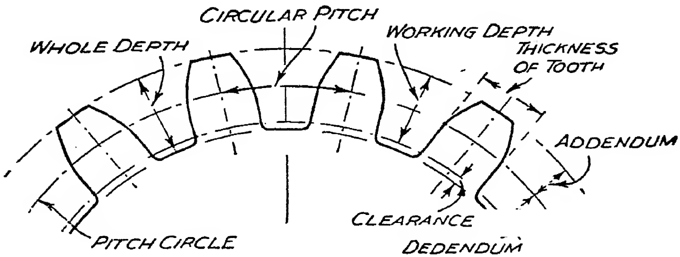


Fig. 235.—The terms used in connection with gear teeth (see tables at end of book).

cutter, which is in itself a gear, shapes the teeth and is itself "geared" to the blank.

Lubricants for Cutting Tools

Material.	*Turning.*	*Chucking.*	*Drilling, Milling.*	*Reaming.*	*Tapping.*
Tool steel	Dry or oil	Oil or soda water	Oil	Lard oil	Oil
Soft steel	Dry or soda water	Soda water	Oil or soda water	Lard oil	Oil
Wrought iron	Dry or soda water	Soda water	Soda water	Lard oil	Oil
Cast iron	Dry	Dry	Dry	Dry	Oil
Brass	Dry	Dry	Dry	Dry	Oil
Copper	Dry	Oil	Oil	Mixture	Oil
Babbit	Dry	Dry	Dry	Dry	Oil

"Mixture" consists of $\frac{1}{3}$ crude petroleum, $\frac{2}{3}$ lard oil. Oil means lard.

RUST JOINTING CEMENT

Iron filings should be mixed with sal-ammoniac in the proportion of 1 to 200, with a trifle of powdered sulphur, and stirred to form a stiff paste. It may be used for filling holes in castings or for "jointing" iron parts which are to be bolted together permanently. The surfaces of the iron to be joined should be quite clean.

SOFT SOLDERING

Soldering.—Soldering is an easy process if simple rules are observed. Cleanliness is important, but not more so than a hot iron and the right flux. It is unreasonable to expect hot solder and flux to remove refractory material whose melting-point is above that of the iron or adhere to material which oxidises when heated.

Fluxes.—Oxygen is the enemy of all forms of uniting metals, as nearly all metals absorb oxygen readily on the temperature being raised, and it is to protect the metals from being oxidised that fluxes are used. An excellent flux for one metal is not so effective on another. Acid fluxes must not be used on electrical connections. The electrical flow sets up some form of electrolysis definitely aided by the minute imprisoned particles of acid, which particles are never entirely removed, however efficient the washing of the part in question.

Chloride of zinc and resin are the two main fluxes used on repairs, although there are many excellent commercial fluxes, such as Fluxite and Baker's Fluid, which are recommended. Chloride of zinc is a liquid, and resin is used powdered. The easiest way to make up chloride of zinc is to dissolve thin strips of zinc in commercial hydrochloric acid. Do this slowly in an open porcelain basin until the acid will no longer "act" on the zinc. When cool, the solution is ready for use, and it should not be adulterated with water. The action of this flux helps to clean the job, and the moment the hot iron touches it, it entirely covers the spot without further trouble. When cold it rests on the surface in isolated globules, but the heating transforms it into a liquid coating, thus excluding

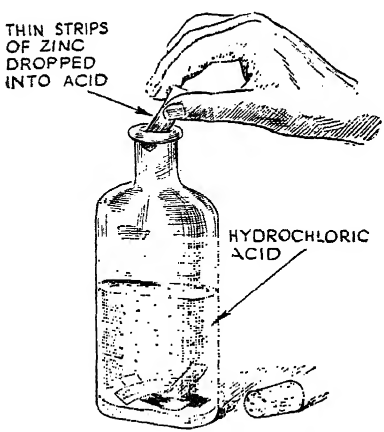


Fig. 236.—Chloride of zinc can be made by dissolving strips of zinc in hydrochloric acid. A porcelain vessel should, for preference, be used.

oxygen from the air, that is, unless the heat is too great and the flux is evaporated. As an iron too cold will not run the solder, so an iron too hot will counter the effect of the flux. A small iron overheated will not, and cannot, take the place of a larger iron which, if anything, is on the cold side. This flux is used on all tinned goods and articles, such as petrol tanks, autovacs, lamp bodies, and petrol pipes, which are "tinned" before soldering. Don't try to solder chromium plating: the chromium must be removed before the solder will take, whatever the flux. Aluminium is only successfully soldered by the professional, and then with special solder and flux. It is not easy, and is often unsatisfactory. An excellent preparation based on zinc chloride is a good soldering fluid. It is better and cleaner than the home-made product and equally as cheap in the long run.

Resin is a difficult flux at all times, therefore Fluxite or Baker's Fluid are far better for general use in every way, and are mentioned because they are non-corrosive and ideal for all electrical joints.

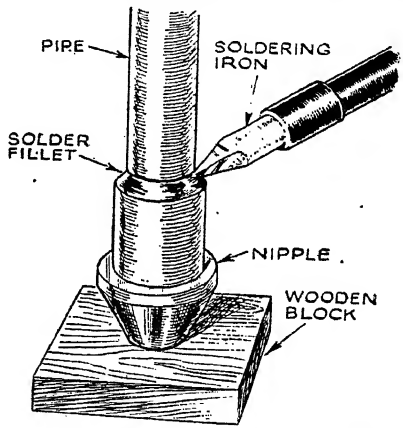


Fig. 237.—The correct method of soldering a nipple to a pipe.

Tinning the Iron.—To "tin" an iron with either of the fluxes, the bit should be cleaned up with a file until the copper is bright. Heat it on the gas-ring until the copper is about to change colour and rub with a stick of solder which has previously been dipped in the flux. Apply it quickly to all sides, afterwards wiping the solder over evenly with a piece of rag. The iron is now "tinned" and ready for use, but there is another method which is equally as good, and that is to have a small piece of tinned steel on the bench on which to rub the iron instead of wiping it with the rag. Both methods apply to both fluxes. When the iron is "tinned," it should still be carefully heated, as a "burned" iron ruins the tin on the surface, turning it into a very brittle dark mass that will neither convey heat nor hold the solder.

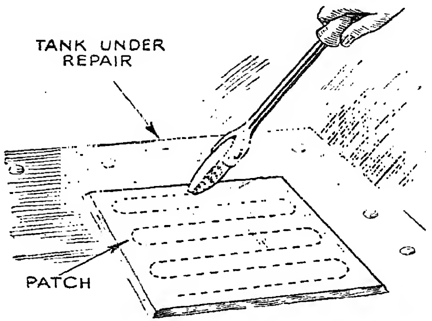


Fig. 238.—When patching a tank, make sure that both sides of the patch are "tinned," thus ensuring an efficient job.

Examples of Soldering.—Many failures are due to the iron cooling off before it can do any effective work, the job carrying off the heat when the iron is applied. The larger the iron the better, as it must hold more heat, also repeated application of a small iron means that the applied heat is flowing away whilst the second heat is being added. Hold the iron still when once applied and watch the effect of the molten solder around it. The solder cannot be rubbed in—it must flow of its own accord. Solder has little strength as a metal, therefore always remember it as the "glue" that holds the work together only. Piling it on the job in the hope that it will overcome the difficulty of your poor workmanship is no use and only failure will result.

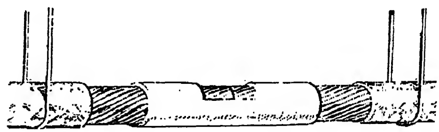
Suppose a nipple is to be soldered on a copper pipe; first, the end of the pipe must be clean and really fit the nipple. The pipe should just slide into the nipple with slight pressure. Dip the end of the pipe into the liquid flux and apply some solder with the hot iron. It will now be "tinned" and will have to be cooled off somewhat. Again dip the end in the flux and tap on the nipple. This "tinned" end will act as a small iron and save the trouble of having to "tin" the small interior of the nipple. Hold the pipe vertically on a piece of wood with one hand and apply the iron with the other hand. As the iron has again been charged with solder, it flows from the iron on to the pipe, where it is already tinned, and so passes down between the nipple and the pipe.

Should the pipe have been a bad fit in the nipple, the hot solder will not only have penetrated between the pipe and nipple, but up the inside of the pipe also, not being able to run out at the bottom on account of the wood acting as a washer. Should this happen, the pipe must be drilled and the shavings from the drill blown out. If too much solder is applied, it is possible to wipe it off before cooling, but it leads to "blobs" where they are not wanted, such as on the cone of the nipple, and perhaps a leaky

union. With practice, the right quantity of solder can be gauged, and if not enough, the iron can, in this instance, be applied again the second time, such process doubly assuring a right soldered joint.

A patch on a tank is also an excellent example of heat transmission by the soldering iron. As usual, clean the place on the tank thoroughly, and " tin " the place to be operated upon about half an inch all round the patch to be applied. The patch should

Fig. 239.—When soldering two wires together, an efficient joint can be made by using sleeving over the two ends, as shown.



be tinned both sides, as the hot solder on the outside helps to convey the heat from the iron to the patch proper, and so to the solder under the patch. The hot iron, supplied with solder, should be slowly and systematically moved over the whole of the patch so that it sticks to the tank at every point, and towards the end the iron is applied to the edges, when, if there is still any air under the patch, it will be seen to bubble out through the molten solder. The iron should only be applied to the edges last of all, mainly to make a neat job and to prove the exclusion of all air. Again, the largest iron possible should be used, especially as it is not always possible to do the job with one application.

In dealing with all electrical repairs, it is again pointed out that a non-corrosive flux must be used, and it is preferable to keep a special iron for such repairs. An iron continually dipped in the liquid flux is bound to impart some of the acid to the electrical joint, eventually leading to trouble. Smear a little Fluxite on the parts to be soldered, as too much is not only a waste, but the surplus paste has a tendency to mess up the near-by insulation. Cleanliness here is a definite injunction, and do not forget to clean the parts to be joined, as the old wires that have become blackened through burned solder must be cleaned with fine emery cloth until they are bright. Dipping the wires in acid is fatal for the same reason mentioned concerning the liquid flux.

Fig. 239 shows the sleeve, bored out so that the prepared wires just slide into the hole. The ends of the wires will be seen at the centre of the sleeve, where a slot has been filed so

that the hot solder can be applied. Place a little Fluxite on the centre of the sleeve where the wires meet, and immediately the hot iron and solder are introduced, the Fluxite will run freely along the inside of the sleeve and between the stranded wires.

Fluxes for Soldering

Metals.	*Fluxes.*	*Fluxes generally Used.*
Iron	Chloride of zinc	Chloride of zinc (killed spirit)
Steel	Sal-ammoniac	
Copper	Chloride of zinc	
Brass	Resin / Sal-ammoniac	Resin
Zinc (new) / Zinc (old)	Chloride of zinc	
Lead (with fine solder)	Hydrochloric acid	
Lead (with coarse solder)	Tallow and resin	
Tin	Tallow	
Pewter	Resin and sweet oil	

Composition of Soft Solders

Solder.	*Composition.*	*Melting-point.*
Fine	1½ parts tin, 1 part lead	334° F.
Tinman's	1 part tin, 1 part lead	370° F.
Plumber's	1 part tin, 2 parts lead	440° F.
Pewterer's	1 part tin, 1 part lead, and 2 parts bismuth	203° F.

A mixture of 1½ parts tin and 1 part lead fuses at a lower temperature than any other mixed proportion of these metals.

Composition of Hard Solders

Solder.	*Composition.*
Hard brazing	3 parts copper, 1 part zinc
Hard brazing	1 part copper, 1 part zinc
Softer brazing	4 parts copper, 3 parts zinc, and 1 part tin

Wood's Metal

A special soft solder used for joining delicate pieces. It consists of 1 part tin, 4 parts bismuth, 1 part cadmium, and 2 parts lead. It melts at about 60° C.

Finding Diameter of Rivets

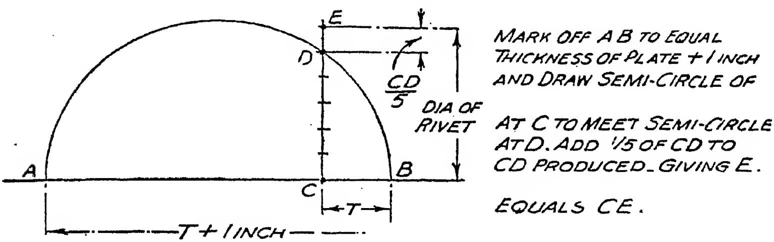


Fig. 240.—Diagram explaining how to determine, graphically, the diameter of rivet required for a given thickness of plate.

CHUCKING CEMENTS

In making very small parts difficulty is experienced in chucking a light or awkwardly shaped article in the lathe. Chucking cement, meltable by heating, is therefore used to grip the object in the lathe. This may consist of pitch 5 parts, plus 1 of alloy, both admixed with 1 part of wood ash. A similar cement can be made from resin, with a slight amount of Venice turpentine in it to render it less brittle.

Another hard plaster cement can be made by melting up 2 parts of resin with $\frac{1}{8}$ part of Venice turps, and a little linseed oil. Glue jelly is prepared and this is mixed in. The compound so formed is again mixed with whiting. When cold the compound is hard, but becomes plastic by warming it. All these cements can be used to hold small metal objects for the purpose of engraving them.

SILVER SOLDERING AND BRAZING

The process of silver soldering is employed in cases where soft soldering would be unsatisfactory on account of the joint having to be subjected to great heat in use, or being insufficiently strong for the purpose. As with a sweated joint the parts are joined by a film of soft solder, so in silver, or hard, soldering they are joined with an alloy containing silver. The chief difference in the operation, however, is that while one is carried out at a

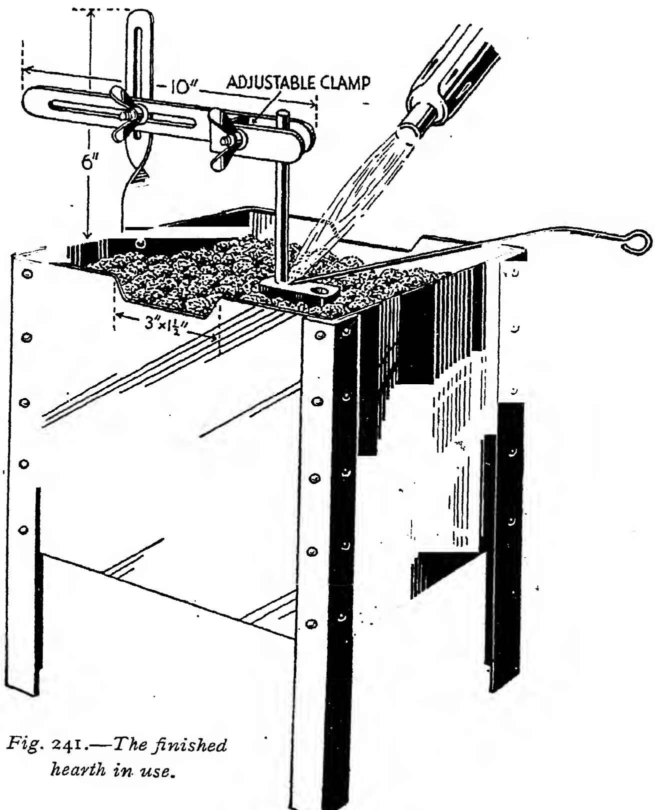


Fig. 241.—*The finished hearth in use.*

temperature of about 400° F., which varies, of course, according to the tin content in the solder, the other requires a red heat.

Heating the Work.—For this reason, some means of heating the work to a corresponding temperature is necessary. A gas blowpipe and bellows are the most convenient heating agency, although for small work a self-blowing or Bunsen type of gas blowpipe is suitable. Failing gas, a good paraffin blowlamp will do the job. With certain classes of work these may be dispensed with, but such conditions will be dealt with later on. With most jobs it is necessary, in order to obtain sufficient heat, to lay the work on a bed of coke, more particularly so for brazing. The following details are given for making a small hearth for this purpose.

A Brazing Hearth with Work Holder.—The hearth about to be described is shown in use in Fig. 241. From this it will be seen that the construction is simple, and could be carried out in a few hours. Provision in the form of an adjustable clamp attached to one side has been made for holding small or awkward work.

The sheet-metal box is 9 in. square × 8 in. deep. These proportions may seem unusual, but the extra depth is to allow for longish jobs that have to be worked upon at the ends. As an example, to silver solder an end cap into a boiler, the job must be stood on end, and to attain and conserve the necessary heat, it is surrounded by coke. Thus it is more certain to build and retain the coke round the job than doing the same job by heaping the coke round it on a shallow hearth.

Mark out and cut the sides and bottom from 18 S.W.G. sheet iron. These are cut in one piece, dimensions being given in Fig. 242; the 3 × 1½-in. sections cut out on the opposite sides are to allow long rods or tubing to lie in the coke when necessary. The four sides are bent up at right angles. Angle iron, 1 × 1 × ⅛-in. section, is used to join the corners and also to form short legs. These pieces are 12 in. in length, and are riveted or bolted on. Black mild steel, 1 × ¼-in. section, is the material for the clamping arrangement. The vertical slotted bar is attached to the sheet metal, with a bolt and wing nut on the outside, so that it may be quickly removed at any time. A ¼-in. cup-head coach bolt and wing nut through the slotted portions form the means of adjusting the work-holding bar. On the end of this a simple clamp is formed by bending the end of a short piece of the flat material to form a heel. This has a square hole in the centre to suit a ¼-in. coach bolt, and a round hole is drilled to correspond in the end of the bar. The bolt is then fitted with a wing nut

and washer. After filling the box with small clean " nut coke," the hearth is ready for use. Should the coke be dirty—clogged with dust—riddle in a sieve, cleanse in a bucket of water, and allow to drain well before using. For small jobs asbestos blocks sold by weight are sometimes used. Where such are employed it is not a bad plan to make a small shallow tray from sheet iron, provided with clips to hook over the sides of the hearth. This can then be lifted off when the full depth of the hearth has to be utilised.

Preparation of Work.—All parts to be silver soldered or brazed must be thoroughly cleaned by scratch brushing (forged parts by filing) to remove any scale, such as is likely to be present on the surface of black-finished steel. The surfaces to be joined should be neatly fitted, and cylindrical parts are made a good sliding fit into respective holes. Driving fits may prevent the solder from penetrating as desired, whereas a sloppy one allows it to run through without filling. Before assembling, paint the surfaces with flux made up to a creamy paste with water. This may be either borax or boracic powder or one of the special brazing fluxes such as " Boron." After assembling, the parts, where practicable, are drilled and pinned, treating the pins with flux before inserting. Where the nature of the work prohibits pinning, iron wire is used for binding. Tinned or galvanised wire must not be employed for the purpose.

With certain jobs, such as the boiler end shown in Fig. 243, a gutter formed by slightly chamfering the

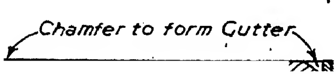


Fig. 243.—By slightly chamfering the end cap of a boiler the silver solder when melted will flow where it is wanted.

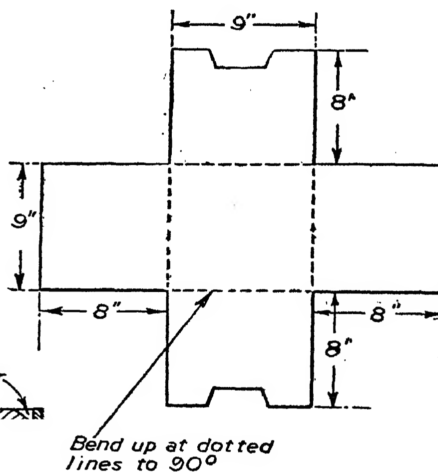


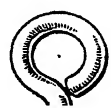
Fig. 242.—Details of the sides and bottom of the hearth.

end cap ensures that the silver solder when melted will flow where it is wanted.

The Choice of Brazing Wire.—For general use on small work silver solder is obtainable in sheet and wire form. This is suitable for all articles likely to be handled by the reader, of steel, brass, bronze, or gunmetal. Silver solder is an alloy, and contains copper, zinc, and silver in proportions governed by the required melting-point. The correct grade for most model engineering requirements is supplied by dealers in model-making requisites.

On larger work, brazing wire composed of copper and zinc is more economical. The most common grade, containing roughly two-thirds copper, is used for steel work. For brass articles it is natural that the wire must have a lower melting-point than the job, and thus a special brazing material is called for. In this the copper content is about one-third ; owing to its brittle nature, the material is supplied in short strips cut from sheet.

Brazing.—Having prepared the work, lay it on the hearth, holding in the clamp if necessary, and build the coke round it, but leaving the portion that it is intended to work upon exposed. Play the flame on to the exposed portion until the part attains the desired heat—a very dull red for brass or bright red for steel—and apply the brazing medium. For the sake of economy silver solder is cut into small pieces and applied with fine tongs, but whatever the medium employed, avoid applying a surplus, so as to reduce the work entailed in cleaning up. Should the metal be disinclined to flow, that is, remain in a small lump or ball, heat the end of a piece of $\frac{1}{8}$-in. iron wire, flattened as shown in Fig. 244, and dip into dry flux. Place this on the work and lightly scrape the surface with it, and as the flux dissolves, so will the metal flow where required. If the



(Left) Fig. 244.—Details of the spatula to aid the flow of silver solder.

Spelter or Silver Solder

Fig. 245.—Another method of hard soldering is shown in the right-hand sketch.

work has been properly prepared and heated, inspection after allowing to cool should reveal perfect penetration of the brazing.

Cleaning Up.—Owing to the nature of the process, a certain amount of cleaning up is necessary. When cool the flux sets hard like glass, and can be cleanly removed by chipping with the edge of a file, when any surplus silver solder or brass is neatly filed off. This scale is readily removable from small or delicate articles by immersion in an acid and pickling bath.

Other Methods of Brazing.—As stated previously, there are other methods of brazing which may be employed for work such as is shown in Fig. 245. This is prepared as previously stated, and granulated brass (spelter) and a little dry flux are placed inside the tube. The end is then placed inside the tube, and inserted upright in a fire or forge until the brass melts.

Small articles can be brazed by covering round the joints with clay or fire cement, leaving an exposed portion at the top surrounded by the clay to form a cup. Granulated brass is put into the cup or cups and heated by placing in a forge in a short length of steam barrel laid horizontally in the fire. The whole job is then heated uniformly, the brass running into the joints. Several joints may be made at once by this method. Owing to the difficulty of controlling the heat with an open fire, these methods, without exception, should be adopted for steel work only.

SOLDERING ALUMINIUM

Success in soldering aluminium depends on the effective removal from the metal of the microscopically thin film of oxide always present on the surface. When measures are taken to deal with this film, the main difficulty of soldering is removed. Three different types of soldering are employed, which may be distinguished by the terms hard soldering, soft soldering, and reaction soldering.

Hard Soldering.—In this process the solder consists of an alloy of aluminium having a melting-point between 500° and 600° C. Many such alloys exist, but the silicon alloy, containing 10–13 per cent. of silicon, is undoubtedly the best. The oxide is removed by means of alkaline halide flux, such as is used for aluminium welding. At the temperature at which the soldering is carried out, the flux is melted and rapidly attacks the oxide, permitting the melted solder to come into contact with clean aluminium and to alloy with the surface. In carrying out the process, a gas blowpipe is used as heating medium, but apart from this and the higher temperature required, the process does

not differ from the ordinary soldering of brass. The flux is melted up and flows readily, sweating the parts together. Certain manufacturers supply silicon-alloy solder in the form of a tube with flux contained inside.

Hard soldering with a silicon-alloy solder is thoroughly to be recommended as regards ease of application, strength, and permanence. Unlike soft soldering, the joint is capable of withstanding the action of boiling water or steam without protection.

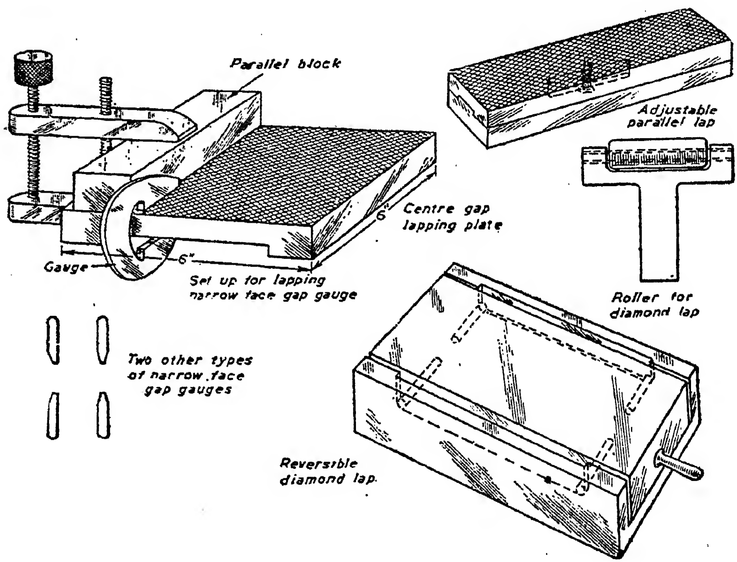
Soft Soldering.—In this process the solder melts at a comparatively low temperature, and it is this type of work which has given rise to the widespread view that aluminium is difficult to solder. The reason is that no satisfactory flux is available which will attack the oxide at the low temperature of working, so that the oxide must be removed by mechanical means. After a preliminary cleaning, the metal is heated until the solder melts upon it. The molten solder will not adhere, but it can be made to do so by scraping through it with an old hacksaw blade or other form of scraper to break up the oxide film. Once the film is broken, the oxide cannot re-form under the solder, and alloying takes place. When the surface is fairly well covered with molten solder, the adhesion is improved by rubbing with a wire scratch brush while the solder is still molten, thus breaking up the remaining traces of oxide. After such " tinning," the parts can be sweated together in the ordinary way. Fluxes are sometimes supplied with these solders, but these consist largely of stearin or resin, and are of little assistance. The composition of the solders is not of great importance. They usually consist of zinc and tin with or without small additions of other ingredients.

Reaction Soldering.—This is a newly developed process which is particularly interesting. The solder is a chemical mixture, which is spread on the parts to be joined and heated by a blowpipe to about 200° C. A chemical reaction takes place, which results in the deposition of pure zinc in a molten condition on the aluminium surfaces to be joined. The zinc flows readily between the edges, and alloys readily with the aluminium, forming an excellent joint. Such joints are much more permanent than joints made by the ordinary soft-soldering process.

LAPS AND LAPPING

There are many kinds of laps in general use to-day; this chapter deals with the making of some of the better-known types, methods of application, and treatment.

The best known type is the ordinary block lap, which is a solid block of good-quality cast iron. A very useful size for this type is 6 in. square and 2 in. thick, because it will fit nicely into



Figs. 246 and 247.—Different types of lap.

an ordinary vice; if a slightly larger block is required for the bench, one with a face dimension of 12 in. by 6 in. will be found to meet most requirements. The sizes of both of these laps have been chosen because they are just within the limits of most medium-sized surface grinders, and so make the truing of the plates a simple operation. (See Figs. 246 and 247.)

Making the Blocks.—First obtain the block of cast iron and machine it all over in a shaping machine, putting a good finish

on both top and bottom. Examine these two faces to decide which is the better, and make this the cutting face. Set up the block in the shaper and cut the grooves on the cutting face; these grooves may be cut either square or diagonal, according to the work to be lapped on the finished plate. If the work is likely to be on a narrow face, the grooves should be diagonal and as narrow and deep as possible—about 0·016 in. each way and making $\frac{1}{4}$-in. diamonds.

The next operation is to drill four $\frac{1}{8}$-in. holes in the base as near to the corners as is practicable and about $\frac{1}{2}$ in. deep. Now place the lap on a surface grinder and carefully clean up the cutting face, taking care to remove all the shaping marks and leave a perfectly smooth surface, showing only the diagonal grooves.

Make four silver-steel pegs $\frac{1}{8}$ in. diameter $\frac{5}{8}$ in. long with a point at one end; harden and temper these pins and push them into the holes provided, with the points protruding. These points will prevent the lapping plate from sliding about the bench during lapping or charging.

Charging is the next operation and may be done in this manner. Obtain a piece of tool steel about $1\frac{1}{2}$ in. square and $\frac{3}{4}$ in. thick, clean it up and harden and temper it, then grind one surface quite flat and smooth.

Decide whether the lap is to be charged with coarse or fine carborundum. Two recommended grades for general work are 3/20 grit coarse, and a special carborundum medium lapping paste. These two will cover most classes of work and produce a good finish. If a high finish is required, use the special finishing compound made by the Carborundum Co.

Smear a little of the chosen compound evenly on the lapping plate, lay the piece of prepared steel on the top, and with a firm even pressure completely cover the whole surface of the plate with a circular motion. When the surface has been covered clean off any surplus compound with a clean cloth and repeat the whole operation once more. A lapping plate charged in this manner will last for some time.

A Lap for Gauges.—The second type of lapping plate shown has a centre gap which is invaluable when small gap or calliper gauges have to be finished. The sizes, methods of manufacture, and charging are similar to the block lap. Fig. 247 shows one method of setting up for lapping narrow face calliper gauges. This particular type of gauge is sometimes required to have a gauge face of 0·016 in. wide, and unless the sides of the gauge are first ground perfectly flat and some means of keeping the

sides perfectly square while lapping is found, the job is not possible.

The set-up shown is very simple; a hardened parallel and a toolmaker's clamp are all the extra equipment necessary; the parallel must, of course, be square. While lapping this type of gauge very little pressure is required, and the parallel must be moved about the lapping plate very frequently to prevent the small face of the gauge cutting into the lap and consequently rounding the edges of the gauge face.

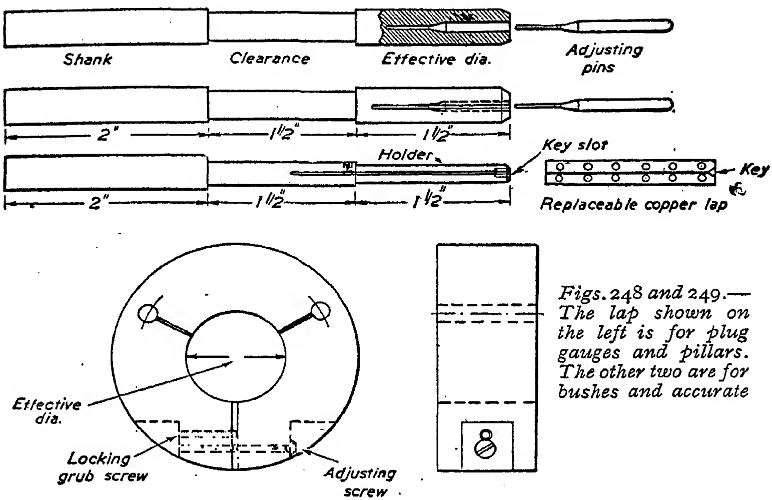
The third lap, an adjustable one (see Fig. 247), is useful when lapping slots or grooves. This lap is also of very simple construction, consisting of two pieces of cast iron held together by a tenon joint. A very useful size is 5 in. long, $1\frac{1}{4}$ in. wide, and when the ends are flush the depth is $\frac{3}{4}$ in. Obtain two strips of cast iron large enough to machine up to the sizes decided upon, bearing in mind that in the first stages one will be at least $\frac{1}{16}$ in. thicker than the other because of the male part of the tenon. In the manufacture of a lap to the above sizes the taper would be about $\frac{1}{8}$ in. in 5 in., therefore the first half would be machined first as a rectangular block 5 in. long, $1\frac{1}{2}$ in. wide and $\frac{7}{16}$ in. thick, and the second half would be made exactly the same except that the thickness would be $\frac{1}{2}$ in.

Making the Lap.—Set up the $\frac{7}{16}$ in. half in a shaping machine and cut in the better side diagonal grooves as previously described. Reverse the strip and set up and machine the taper and then machine in the centre a slot $\frac{3}{8}$ in. wide and $\frac{3}{32}$ in. deep; the slot must have the same taper as the back of the strip. The second strip should now be set, and the same taper put on one side. Then remove sufficient material from each side to leave a bar in the centre $\frac{3}{8}$ in. wide and $\frac{1}{16}$ in. deep. This bar should be a good sliding fit in the slot provided. Put the two halves together and from the back put a 4 B.A. tapping hole into the centre $\frac{9}{16}$ in. deep. Separate the halves, tap the top, open out the hole in the bottom and countersink it. Put the halves together again and this time fasten with a countersunk screw. Surface grind both top and bottom in order to make sure that they are both perfectly flat and parallel, charge the cutting surface in exactly the same manner as for the other lap, remove the screw, and the lap is ready for use. It will be obvious how easy it is to true-up this type of adjustable lap, and as only about 0·0005 in. need be removed from the surface during each true-up it will be some considerable time before the grooves will need recutting.

A Diamond-charged Lap.—The last type of lap shown in

Fig. 247 is extremely useful and hard wearing if reasonable care is taken in the matter of cleanliness, and only hardened jobs are lapped on it. It is a diamond lap charged on both sides, fitted into a frame to enable the lap to be turned over without the faces touching the bench.

This lap is made of mild steel, and may be made as large as possible. If facilities are available for machining (not surface grinding), a good size would be 18 in. square and 2 in. thick. Shape or plane the top and bottom and two sides, putting on a



Figs. 248 and 249.—The lap shown on the left is for plug gauges and pillars. The other two are for bushes and accurate

good finish ; lay the two surfaces on the bench and scrape until they are quite flat. This is very important.

With a two-sided lap it is obvious that one should be rough and the other smooth, therefore charge one side with diamond powder of about 280 grain and the other side with 400-grain powder.

The method of charging this diamond lap is slightly different from that already described because the diamond powder has to be forced into the lap under considerable pressure. Moreover, in view of the cost of the powder, no waste can be allowed. One economical and very effective method is to make up a mild steel holder of substantial dimensions, shaped like a fork, the stem being made to fit into the toolpost of a planing machine. Then

turn and harden a tool steel roller to go between the jaws of the fork. The method of charging is now obvious. Smear a thin coat of diamond powder on the lap as evenly as possible. Return the lap to the machine, set up the roller, as though it were a cutting tool, quite square with the plate and proceed to roll the whole surface in the ordinary way. It may be necessary to smear a second coat of diamond powder and repeat the rolling process, applying as much pressure to the roller as is practicable.

The second side should be treated in a similar manner, using the other grade of powder.

The service of these two lapping faces may be counted in years if, as stated before, only hardened work is used upon them. The reason for stressing only hardened work is because the lapping plate is soft mild steel, and however carefully the faces are charged there are always small parts slotted all over which have no charge; when a soft steel job is being lapped the uncharged parts of the lap "pick up" on the job. This will result in score marks on both lap and job, while the groove will uproot the diamond particles in its track, and eventually the plate surface will be ruined.

Renewing the Surface.—If the plate does become scored and spoilt, and a new surface has to be put on it, the procedure is very different from any of the other laps, which have only to be cleaned up on a grinding machine. This lap being charged with the hardest known substance will not respond to such treatment, and the following method must be adopted: Place the plate on the planing machine and take off a cut $\frac{1}{32}$ in. or more in depth, using a tool with a good side rake which will begin cutting the plate below the surface. Then scrape and recharge in the manner already described.

The frame to hold the plate is very simple, consisting of two suitably dimensioned sides milled to allow the four pegs, which are fitted into the machined sides of the lapping plate, to rest as in a nest and prevent it from moving about during work. The sides are held apart by two straps fastened on the ends.

To turn the plate over, fit a handle in one of either two sides, lift up the plate by this handle, slide the plate along the nest on the two back pegs and lower the plate on the other side.

The face of the lap being used should always be proud of the frame, to prevent damage to the work by accidental knocks, and to prevent the centre of the plate wearing before the sides.

There are, of course, other methods of turning the plate over; one is by making a frame to stand on the floor, holding the plate by two centre pins, like trunnions, and merely swinging the plate

round. Two suitably placed stops would be needed for holding the plate while lapping.

Lapping Gauges.—The lapping of plug gauges and other round surfaces, such as pillars for die sets, calls for a special method of procedure and equipment. Figs. 248 and 249 show one type of adjustable lap capable of lapping this type of work to extreme limits of accuracy.

The manufacture of and the method of using this lap, if carefully carried out, will enable anyone with engineering experience to perform work of an accurate nature quite satisfactorily and with confidence.

First obtain a piece of first-quality cast iron of suitable dimensions. As a guide, a lap for a 1-in. plug gauge would be about $2\frac{1}{2}$-in. diameter and 1-in. thick. Face and bore out the hole in a lathe, paying particular attention to the bore, which should be the exact size of the plug gauge and have a dead smooth finish. The reason for this is obvious, because if the hole is not the correct size to start with the lap will not have a true form when it is being used on the first gauge, with consequent inaccurate lapping. If the bore is not dead smooth there will be very rapid wear.

Space out three points on a pitch circle diameter of 2 in., suitable for the 1-in. lap, and using a centre square or other suitable means, scribe a line from each of these points to the centre. Centre-punch two of these points and drill a $\frac{3}{16}$-in. diameter hole. Now saw down the scribed lines, starting from the bore and finishing at the $\frac{3}{16}$-in. hole.

Two recesses should now be end-milled in the periphery of the lap, using the third and as yet unused scribed line as a guide to set to, thus ensuring the base of the recess being square to and parallel with this line. Drill two 2 B.A. tapping holes from one of these recesses. The first one should go right through to the other side and the second one about $\frac{1}{16}$ in. past the centre line. Saw down the centre line as shown in Fig. 248.

The first of the 2 B.A. tapping holes should have a 2 B.A. clearance drill put through just past the centre and then tap out the remainder. The second hole should, of course, also be tapped. Put a round- or cheese-headed screw in the first hole, making sure that the head of the screw does not stand proud of the periphery of the lap. This is a safeguard for the hands. In the second hole put a 2 B.A. grub screw. The first screw will govern the size of the bore and enable the operator to put a little more pressure on the lap if necessary. The grub screw will lock the lap while lapping is being done, and enable the operator to ease

the pressure if required. Remove all burrs and sharp corners, and the lap is ready for use.

Using the Lap.—The type of work for this lap is always cylindrically ground with a high finish and to within ·0003 in. plus of the top limit size. The method usually adopted is to set the lap just to hold the plug gauge, place the gauge in a lathe, run the lathe at medium speed, use the slightest smear of carborundum finishing compound and, holding the lap by hand, move it slowly up and down the full length of the gauge ; any surplus compound will find its way into the saw cuts.

When extreme accuracy is desired it is essential that the gauge be checked for size very frequently, and that the size be measured on an electrical comparator. These instruments are positive, and independent of the operator.

The required gauge size is built up on two combinations of slip gauges. The reason for two combinations is that if one shows different from the other, one has obviously dust or moisture between the slips. When these two sets are dead right when measured on the comparator, take the plug gauge and thoroughly clean off all traces of lapping compound, making absolutely certain that the work is quite cool. It is usual to allow both slips and work to lay on a face-plate for a little while until all are the same temperature. Set the comparator to zero, using the slips, and then pass the work through. The difference is shown on the scale. The lapping and testing must now be continued until the comparator shows zero for both the slip gauges and the work.

Points to watch are the need for scrupulous cleanliness, cooling after each lapping, and frequent testing on the comparator, always using the slip gauges first and the work afterwards.

Lapping Out Holes.—The illustrations (Figs. 248 and 249) also show two views of a lap commonly used for lapping out holes ; this type is easily and quickly made and is also adjustable. Mild steel may be used. The length of the complete lap varies according to the length of the hole to be lapped, although a fair average size would be about 5 in. over all, $1\frac{1}{2}$ in. effective lapping surface, $1\frac{1}{2}$ in. of clearance, and 2 in. for holding in either lathe or drilling machine.

First centre both ends of the mild steel bar selected, say $\frac{7}{16}$-in. diameter, for a $\frac{3}{8}$-in. diameter lap. It is important that laps of this type are turned between centres. Set up and machine the effective diameter first, leaving on about ·005 in. Machine the clearance diameter and then just clean up the shank. Finish off the effective diameter to size, putting on a good finish, and

finally put a $\frac{1}{16}$-in. chamfer on the end. Place the lap in a collet, if possible (this may be done by putting the lap through the back of the collet before putting the collet in the lathe), or use a self-centring chuck and drill the hole for the adjusting pin. First drill $\frac{3}{4}$ in. with a long-pointed $\frac{1}{8}$-in. diameter drill, and then a further $\frac{3}{4}$ in. with a $\frac{3}{32}$-in. diameter drill.

Remove from the lathe, and with a jeweller's saw or similar thin-bladed saw, saw right through the centre almost to the end of the effective diameter. Run a smooth knife-edge Swiss needle file up the saw-cut to remove all the burr, and revolve the two drills in their respective holes for the same purpose.

The adjusting pin comes next. This is made of silver steel, hardened and tempered, one end being turned down to $\frac{3}{32}$-in. diameter for $\frac{1}{2}$ in. of its length, followed by a taper running from $\frac{3}{32}$-in. to $\frac{1}{8}$-in. diameter in $\frac{1}{4}$ in. of length and finally the $\frac{1}{8}$-in. diameter about 1 in. in length. This will leave $\frac{1}{4}$ in. at least always protruding, and if the holes in the laps are made standard, one adjusting pin will serve for all of them.

Replaceable Lapping Surface.—The fourth lap shown in Figs. 248 and 249 is somewhat similar to the other two in principle, the difference being in the means of adjustment, while the actual lapping surface is replaceable.

The holder is made of mild steel as before, and in making a lap for a $\frac{3}{8}$-in. diameter hole the length would be about 5 in. and the diameter $\frac{7}{16}$ in. Turn between centres as before, cleaning up the shank and turning down the clearance space, and finally turn the part which would normally be the effective diameter. This time only a holder is made, $\frac{1}{16}$ in. less in diameter or $\frac{5}{16}$-in. diameter. File or mill a key slot in the end of the holder as shown in the sketch. Saw through the centre with a jeweller's saw, going about $\frac{1}{2}$ in. past the length of the effective diameter. Remove the burrs as before.

Midway between the end of the lapping surface and the end of the sawcut, drill and tap a 6 B.A. hole and fit a grub screw. This grub screw, which is case-hardened, should be in length half the diameter of the clearance space, plus half the width of the sawcut.

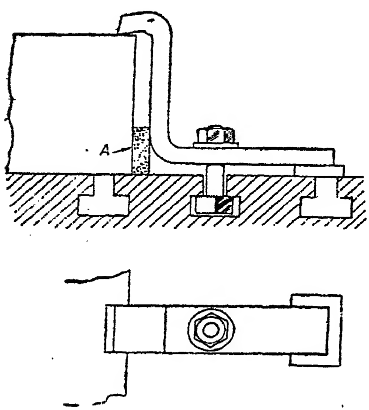
The second part of this lap consists of a copper or soft brass sleeve. This sleeve is as long as the holder, and should in the first place have a series of $\frac{1}{16}$-in. diameter holes drilled in parallel lines right round the periphery, leaving only a solid bar of metal about $\frac{3}{16}$ in. wide. This bar has to be sawn through at the end.

The most common way of using all of these three laps is in a sensitive drilling machine.

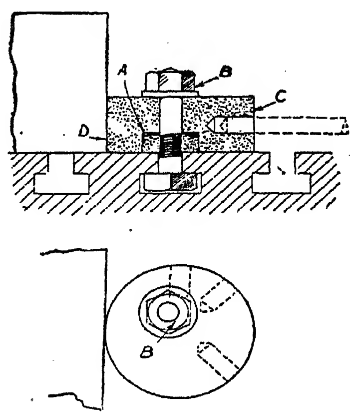
CLAMPING WORK TO MACHINES

Usually work to be milled or turned has some flange or projection by means of which it may, by the ordinary clamps and bolts, be fastened to the machine-table or the lathe face plate for grinding, shaping, turning, milling, etc. But where the operator has to machine parts with straight sides, no flanges and little head room above the surface, the usual simple clamps are unsuitable and often impossible of application.

The arrangements shown here will apply to these jobs generally.



Figs. 250 and 251.—Side view and plan of a simple dog of cast steel.



Figs. 252 and 253.—A device for use in conjunction with a stop block on the other side of the work.

In Figs. 250 and 251 is shown in side view and plan a simple dog of cast steel. The top turned-over edge is hardened and ground and is slightly inclined. The base is approximately horizontal and is slotted for a bolt, which is held by its head in the T-slot of the machine table or the radial slot in the lathe face plate. If the dog is placed close to the work, or a piece of packing is placed at A, it can be made to secure the work endways as well as to clamp it down on the table or face plate. Sometimes this is necessary to take the thrust of the cut in milling, shaping, or planing.

A device that is not quite so simple, but easily made, and one

which holds the work tight on the table and against the cut, is shown in Figs. 252 and 253. It is used, as are most of the other devices shown here, in combination with a stop block on the other side of the work opposite to it. The latter is not shown in the sketch.

The stud or bolt is fitted in the T-slot of the machine table and held down by the hexagon nut A. The rest of the stud or bolt is plain for most of its length, and of a diameter equal to the bottom diameter of the thread carrying the hexagon nut A, and at the top it is threaded to its full diameter to take the top nut B with a washer below it. The block C is of cast iron and is cheese shaped. The hole through it is eccentric to its outside diameter, as seen in the plan view. When rotated, therefore, it acts as a cam and can be pulled round by a tommy bar. The holes for the tommy bar are indicated in the plan view. This will give enormous side pressure on the job—enough to hold it tightly against the opposite abutment.

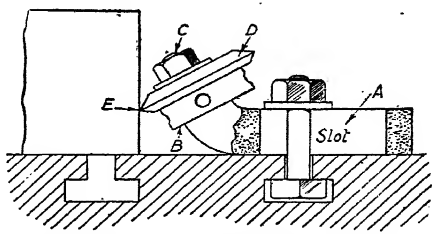


Fig. 254.—*An eccentric cam device for holding large jobs.*

For Larger Work.—Where the size of the work makes it difficult to so place it that the T-slot comes at a convenient distance away from the side of the work and allow the cam block to come up to the work when turned, packing can be inserted at D between the cam block and the work.

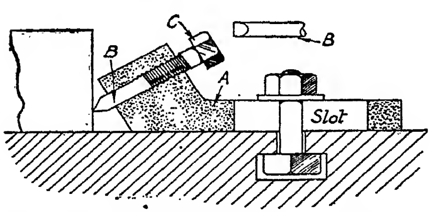


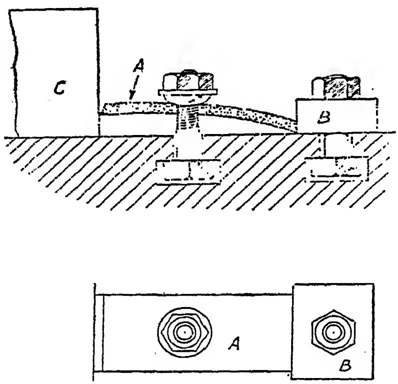
Fig. 255.—*A simple adjustable dog acting on direct screw pressure.*

A similar application of the eccentric system is shown in Fig. 254. Here the device also positively holds the work down tightly to the table. The block A is of cast iron and has an inclined surface at B, into which is screwed, very tightly, a cast-steel stud, C. The block A is slotted for convenience in setting it on the table, and is held down by the usual bolt and nut in the table T-slot.

The cam, in this case, shown at D, is mounted eccentrically

on the stud C and is of cast steel with a V-edge periphery as at E. The eccentric is recessed below the sharp edge and drilled with the radial holes for the tommy bar as in the arrangement shown in Figs. 252 and 253. The cam should be hardened and tempered to a full straw colour on its periphery—the sharp V-edge. Having heated and cooled it and so made it dead hard, the temper can be drawn at the edge by placing a red-hot bar in the stud hole and watching the colour come along to the periphery.

The turning of this eccentric not only forces the work along against a stop at the other side but also forces it down by the sharp edge, gripping into the surface of the side of the work.



Figs. 256 *and* 257.—*A holding device made of spring steel.*

A Spring-steel Clamp.—In Figs. 256 and 257 is shown a novel clamping method, which has been found very effective. A curved piece of coach spring A of good thickness is bent to the arc shown and a centre hole drilled in it. It is ground square at the ends and then tempered by heating red hot and quenching in cold water on the surface of which is a layer of oil. Its application is shown. It abuts at one end against the bolted-down block B and at the other against the work. The bolt passes through the hole in its centre, and when the nut is screwed down the arched spring steel tends to flatten and thus exerts a very great pressure between the abutment block B and the work to be held C. The ends of the spring arch A are ground to the angle shown at the end which contacts with the work so as to grip the work and exert a downward as well as a longitudinal pressure.

In Fig. 255 is shown a simple adjustable dog acting on direct screw pressure. The dog A is of cast iron and slotted to take the holding-down bolt and nut as shown. At the thickened end it is drilled to the angle shown.

METHODS OF RIVETING

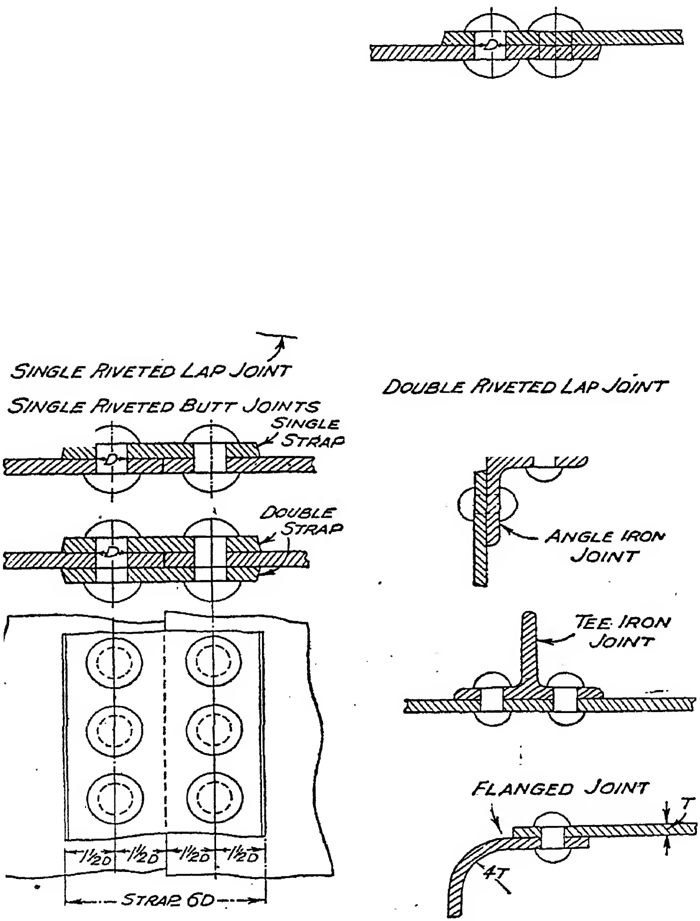
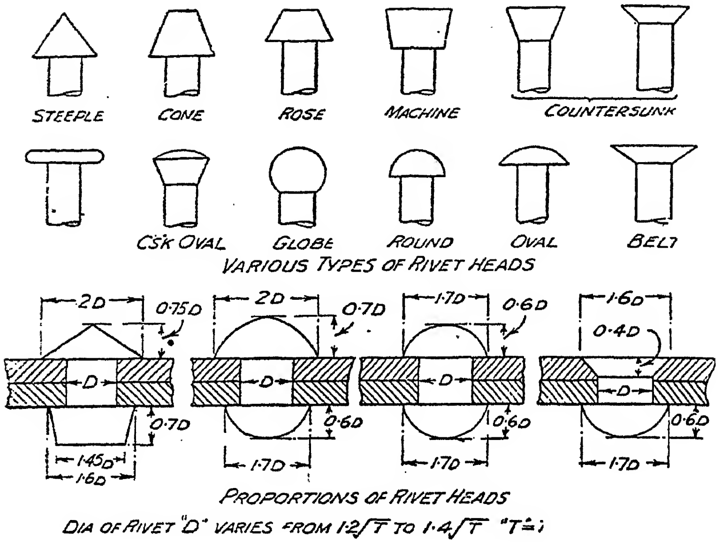


Fig. 258.—Various styles of riveted joints.



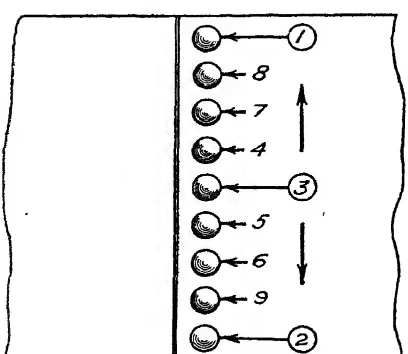


Fig. 259 (*Above*).—*Various types of rivet and their proportions.*

Fig. 260 (*Left*).—*The order of setting rivets to maintain coincidence of holes. The two end rivets should be inserted before closing them. Insert all other rivets before setting to maintain location, and close them in the order given.*

POLISHING AND FINISHING METAL

No mechanic can afford to ignore the art of finishing metal-work, and this section explains main details of the processes involved. Many engineers' workshops can be greatly improved by the addition of a few polishing and emery wheels, provided, of course, that there is power available to drive them. Once the "kit" is purchased (cloth wheels, emery wheels, soaps, etc.), there is practically no further expense, as the materials are very lasting, even with hard usage. Every kind of polishing job which is finished off with polishing mops is very much more satisfactory than the job which is simply wiped over with a rag. In this section is given details of the art of polishing, and solutions to many problems which the novice may meet.

Power Necessary.—The first obstacle which crops up is the question of power. Quite frankly, if there is a lot of heavy buffing to be done, at least a 1-h.p. motor is required with a

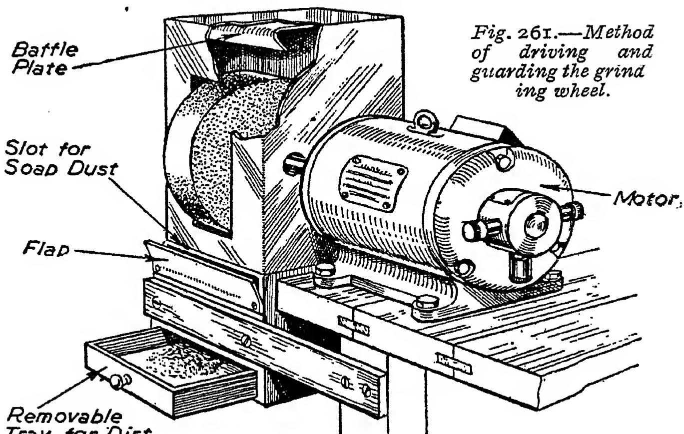


Fig. 261.—Method of driving and guarding the grinding wheel.

speed of 2,000–3,000 revolutions per minute. A squirrel-cage motor is most suitable for the purpose as regards economy and stability. Such a motor will answer the purpose for every phase of first-class polishing. On the other hand, a light polishing machine can be driven by a $\frac{1}{6}$-h.p. motor, which will be found quite satisfactory, enabling all metals of fairly good surface to be brought up to a very nice finish.

In large factories the polishing shop is particularly interesting. There may be anything up to thirty wheels of different kinds and speeds, being driven from overhead pulleys. An enormous amount of dust is created by the wearing away of wheels, but the water helps to counteract this. The real idea of the water, however, is to act as a sort of lubricant, enabling the work to be turned out to a fine degree of finish; the water is kept trickling down on the rapidly revolving wheels.

Preparing Castings.—When castings come out of the moulds they are first ground on coarse emery wheels, where all the bumps and hollows are removed, then passed on to finer wheels, until eventually they are cloth polished with a super-finish soap, and a very high-speed wheel.

Regarding the different wheels which are used: the emery wheel is simply made of wood or felt with a sheet of emery cloth glued round; it is a constant source of trouble, inasmuch as it is extremely difficult to get it to run on its spindle perfectly true. The central hole in the wheel is usually too large for the spindle, and to overcome this the wheel is often clamped up tight. If much pressure is put on such a wheel it will shift, and if it does, it will play havoc. Even when they are only slightly out of true they make considerable noise when in use.

Mounting Emery Wheels.—A good remedy for this is as follows: turn a piece of steel the exact diameter of the spindle on which the wheel is to be mounted, and place it into a piece of wood, as shown in Fig. 262; then place the emery wheel on the wood. Care must be taken to get the spindle set square in relation to the wood. Place the wheel as central as possible, and measure carefully from the outside edge of wheel to the opposite side of shaft, continuing all the way round. The distance at which to set the callipers is easily calculated from the diameter of the wheel and the spindle. When all is carefully adjusted, pour in molten lead, filling up the space between the spindle and the hole in the wheel. This method will be found to give excellent results. When clamping up the wheel a couple of cardboard disks inserted between the clamping washers and the wheel will increase the driving friction without tightening up too much with the risk of cracking the wheel.

Having fixed up the emery "bob," a few words concerning its use will be helpful. When using a bob it is important that a plentiful supply of grease or oil be used as a lubricant, otherwise the casting will turn out a burnt colour which cannot be removed; this, of course, is owing to the excessive friction caused when

grinding. When the metal to be polished contains scratches, they should always be removed in this manner.

Cloth Wheels.—Next come the cloth wheels. These are made chiefly of linen sheets piled together. On some wheels these sheets are stitched together and are called stitch mops; they are used for "roughing"; owing to centrifugal force, these wheels are quite hard when running. Another serviceable "mop" is the scratch mop, and is made of wire bristles—a most excellent tool for scratching off old rust, etc. The lubricant used on the cloth chiefly consists of bath brick and rotten stone, and a super-finish soap which is made of lime. The lubricant should be constantly rubbed on the wheel, and the latter should never run dry or shiny, otherwise it will not polish efficiently. To remove

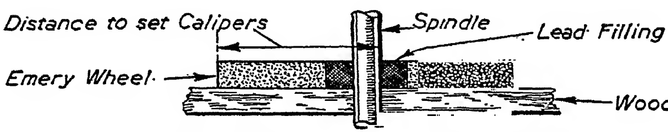


Fig. 262.—Method of mounting emery wheels.

scratches, keep applying a fair quantity of soap, and let the wheel rub on the one spot for a while. When all the scratches are removed it is time for a final finish. This should be done on another wheel, using the lime soap. The operator should work systematically, that is, start at the bottom and work in a horizontal motion, upwards; when done in this manner the job will have no "wheel marks" in it. The work in hand, especially on a high-speed motor, should always be gripped firmly, and on no account should a sharp edge be allowed near the wheel, or else it will tear the job from the operator's hands. These remarks are most important, and an amateur will soon see for himself that there is quite an art in getting a perfectly glassy surface. If, however, the job is carried out as above, a really excellent finish can be obtained. Any dirty soap marks which still remain on the work can be easily rubbed off with a drop of petrol.

Brushing Wheels.—Another class of wheel is the "brushing" type, under which class come brass-wire, steel-wire, and nickel-silver-wire wheels.

The brass-wire fine wheel is used for putting a fine dead surface on coloured gold work, for finishing sand-blasted gold and silver, and for producing a very dead finish on silver work. The medium brass-wire wheel is used for coarse frosting and scratching before

plating, and also for bronzing, brassing, coppering, etc.; while the coarse-type wheel is for scratching before burnishing, and for cast brass, copper, and iron articles after pickling.

The steel-wire fine wheel is used for all work requiring a coarse dead frost, and for bronzed jewellery, bronzed brass, and copper work. The fine type is for frosting aluminium and general scratch brushing, while the coarse type is for heavy work, castings, etc.

Finally, the nickel-silver-wire wheel is used for retaining a white finish on silver and nickel, and also on aluminium articles prior to chrome plating.

Spindle Speeds.—The speed at which brushing wheels are revolved is an important matter. It should be remembered that wire wheels must always run more slowly than bristle or fibre wheels; also that the larger the wheel and the coarser the wire, the more slowly it must revolve. The following speeds are recommended for average working conditions:

Small bristle and fibre wheels . .	2,500 r.p.m.
Large bristle and fibre wheels . .	2,000 r.p.m.
Fine-wire scratch wheels . .	1,600–1,700 r.p.m.
Medium-wire scratch wheels .	1,200–1,500 r.p.m.
Coarse-wire scratch wheels .	700–1,000 r.p.m.
Extra heavy wire scratch wheels	500–600 r.p.m.

To prevent wire brushes and wheels rusting when not in use, lay them in a basin of water in which a little lime has been added.

If the dust created by the wearing of these wheels becomes a serious question, a guard can be made, as shown in Fig. 261.

The guard is made from sheet steel, bent to shape, and riveted. The baffle plate should be set at such an angle as to prevent the air from rushing through the slot for the wheel.

A Polish for Brass and Copper.—Take ¾ lb. of rotten stone, 1½ oz. of oxalic acid, and ¾ oz. of gum arabic. Finely powder these ingredients, then make a paste by stirring into the dry ingredients 1½ oz. of sweet oil and as much water as necessary.

Hints on Polishing Ebonite.—To polish ebonite thoroughly is a very tedious operation. Most of the work required by the amateur may conveniently be polished in a lathe. After having cut the piece out roughly with a hacksaw, file it to size, using a rough file and taking care not to scratch it on any side that may be already polished. Next use a smooth file on it, finishing up with a "dead" smooth file. Having proceeded so far, the work may be taken to a lathe. First use a rather coarse emery wheel,

keeping it revolving at a high speed, and above all, for the reason aforementioned, use plenty of oil. Continue using emery wheels, finishing up with a "dead" smooth one. Do not use a finer wheel until all the scratches produced by the previous one are removed by the wheel then being used, for this is the cause of nasty scratches appearing on an otherwise finely polished surface, and to attempt to remove them afterwards requires a large amount of time.

Having arrived at this point, the work should begin to present a fairly good surface. The next step is to use a cloth wheel, using plenty of soap and water. This operation will take considerable time and energy unless the amateur has "power" for his lathe.

During the whole of the polishing operation, care should be taken to see that the corners of the work are kept "sharp."

The ebonite should now present a fairly good polish, and it will, in most cases, suffice for the amateur to stop here; but if he desires to obtain a still higher polish, he may do so by proceeding as in the last operation, using rotten-stone soap. It will be found that, if this method is carried out carefully, excellent results are obtainable.

USEFUL IRON CEMENTS

A good fire-resisting iron cement is to be made by mixing iron filings with twice the volume of dry clay powder. Make up a solution of borax and salt, adding half as much pyrolusite (manganese dioxide) as there is iron filings. Mix the latter with the iron filings and clay powder, using at once.

Sal-ammoniac in a saturated (i.e. strong) solution, and iron filings, make a good cement for ironwork. Another cement is composed of clay, iron filings, vinegar, and water in the proportions of 10, 10, 2, and 3 respectively. Sometimes sulphur is added to the sal-ammoniac mixture, mixed up with a little weak sulphuric acid.

For making up the joints of iron tanks, iron filings mixed with vinegar, and a little clay powder to give it a consistency, is recommended.

A black cement for ironwork may be concocted by mixing iron filings, fine sand, bone, black slaked lime, and glue water.

HEAT TREATMENT

Steels, from the point of view of the subject under consideration, may be divided into two broad classes, namely, those which will respond to a treatment consisting of heating and quenching followed in some cases by tempering, and those that require the addition of further carbon before the quenching can produce the desired result.

The Effect of Heat Treatment.—Heat treatment may be necessary to restore the material to its normal condition after working at a high temperature, or in the case of certain alloy steels like nickel, nickel-chrome, and chrome-vanadium, a hardening and tempering process is carried out, after which the steel although hardened is still in a machinable condition. Such steel, unless required for forging, is usually supplied in a hardened and tempered condition. Steels of this description are, after treatment, relatively harder than a normalised sample, but the object in this instance is to produce in the steel the maximum mechanical properties, excluding a glass-hard surface. Where this latter property is required in addition, a case-hardening nickel or nickel-chrome steel is employed.

The effect of heating a piece of steel to its hardening or critical temperature is the cause of change in the micro-structure of the material. If allowed to cool slowly the structure reverts to its normal condition, but if arrested at that point by rapid cooling it becomes hardened. The temperature and degree of hardness vary with the carbon content (which is the hardening agent) of the steel. The higher the percentage of carbon present the lower is the hardening temperature, thus a cast tool steel containing 1·4 per cent. carbon will harden at a lower temperature than one having 0·5 per cent. Incidentally, both steels are used for different classes of work, and whilst the former will produce the glass hardness requisite for machine cutting tools, the lower grade is intended for such services as providing a comparatively thick, hard surface, or end, on a low-carbon steel when the two are welded together and subsequently hardened.

Hardening Methods.—The means used to bring the material to the desired temperature before quenching may consist of an open fire, torch, muffle furnace, or other device specially constructed for the work. While an open fire may be suitable for hardening such articles as cold chisels, good results are not likely to follow from a general adoption of this practice.

The first essential of good hardening practice is to secure uniformity of temperature, and where a flame is impinging directly

on to the work the attainment of such a condition is impossible. This is particularly so where the mass of the steel being hardened is unevenly distributed, as, for instance, in a screwing tap. Such a part is bound to receive most heat at the thinnest points, namely the threads, when the resultant hardening would be unsatisfactory. Another important point is the prevention of scale formation appearing on the work during heating. This is almost impossible where the work is open to the atmosphere during the process. Further to this, some means of temperature control is necessary, meaning that some form of chamber is required in which the heating of the part can be carried out to ensure that uniformity of hardening may be repeatedly attained with assurance.

Muffle Furnaces.—Suitable furnaces may be heated by gas, oil, or electricity. Briefly, they consist of a firebrick-lined chamber fitted with a door to permit the entry and removal of work, the interior of which is capable, by regulation of the heating medium, of being maintained at the desired temperature for the requisite period.

Certain forms of this class of furnace for the hardening of large quantities of small articles are arranged for continuous operation, the parts being fed on to a moving chain grating travelling at such a speed through the heated chamber that they are ready for quenching when they have passed through. On emerging from the furnace the parts fall off the end of the grating directly into the cooling bath.

Hardening Baths.—Another method is to immerse the parts to be hardened in a bath of molten lead or metallic salts which is maintained at the desired hardening temperature. This method is particularly suited for the hardening of slender or intricate parts in the nature of taps, dies, and light parts. The advantage of this method is that no portion of the work can reach a temperature other than that of the bath, and therefore absolute uniformity of heating results.

Indication of Temperature.—The use of a pyrometer is a necessity where hardening is an operation that is regularly carried out. Most common of these is the thermo-electric type, in which the action of the heat on the thermo-couple, housed in a tube inside the muffle or in the bath, creates a current which is registered on a meter calibrated in degrees Fahrenheit or Centigrade. Other forms are the resistance and optical-type pyrometers.

Another method that can be employed where the amount of hardening does not warrant the adoption of more expensive but nevertheless reliable apparatus is the Sentinel cone. These

cones are composed of mineral salts or substances which are placed in the hardening chamber. The cones are graded by means of numbers, indicating the temperature at which they melt. Thus a cone is selected which will melt when the interior of the furnace reaches the desired temperature. When such are employed the directions for use should be carefully studied.

Judging Temperatures by Colour.—The judgment of high temperatures by colour can be, by skilled persons, estimated with fairly close approximation. However, the conditions of lighting under which the viewing takes place cannot be constant, and therefore may be considered unreliable, depending as it does so much upon the skill of the operator. As an aid to such judgment a colour chart ranging from dull red (515° C.) to white (1,320° C.) is sometimes included in a steel manufacturer's list. A chart of this description is certainly handy, and it is intended to be used in daylight, but it naturally follows that on a dull day the colour of the heated metal may appear brighter than is really the case for purposes of comparison.

Lower temperatures are more easily judged (where the steel is polished) by the colour of the oxide film which appears on the heated surface. The colour ranges from pale straw (220° C.) to dark blue (316° C.). Here again temperature charts are available for comparison. In both cases, however, the colours are dependent on the colour printing and should be taken as a guide only, experience being gained in the light of the results obtained.

Quenching.—Having heated the steel to the correct hardening temperature, or slightly in excess to allow for temperature drop during transfer to the bath, the part being dealt with is immersed in the cooling medium. The object should be in the majority of cases to secure cooling at an even rate and as rapidly as possible. The nature of the coolant is dictated by the class of steel used and may consist of water, water and oil, brine, oil, or air.

High-carbon steel hardens in water, and if the formation of the part made from this material is such as is likely to induce the formation of hardening cracks a layer of oil is sometimes used on the surface of the water. Most of the tool steels now in use fulfil the same purpose, but are oil hardening, in which the risk of deformation and cracking is greatly minimised if not entirely eliminated.

Where the bath is being frequently used or the mass to be hardened is sufficient to cause an appreciable rise in the temperature of the coolant, some means of dissipating the heat generated is introduced. The means used generally consists of water cooling, either by circulating the coolant through pipes surrounded

by water or circulating water through pipes situated in the cooling tank.

For water hardening, clean water should be used at a temperature not lower than 60°. Soft water is preferable to hard, and it is often beneficial to introduce a proportion of washing soda to the water to create this effect. Hardening oil should have a high flash-point, be comparatively thin, and not readily become gummy. Special oils are made for this purpose.

There are available carbon steels having a low carbon content which do not respond to direct heating and quenching and which may be surface hardened after treatment to introduce additional carbon. This process is known as case hardening. The hard case so obtained is in the form of a skin, the depth of the case depending upon the duration of the process employed.

In thickness the case may vary according to circumstances from a mere skin of a few thousandths of an inch to anything up to $\frac{1}{8}$ in. This is entirely dependent on the service for which the part is required and if a proportion of the hard surface needs to be subsequently removed by grinding. For ordinary commercial purposes the depth of the case ranges from $\frac{1}{32}$ in. to $\frac{1}{16}$ in.

The simplest method of case hardening is to heat the steel to a bright red and either apply "rapid" case-hardening compound by dusting on to the heated surface or rolling the part in the powder. After allowing sufficient time for the compound to melt on the surface of the work, it is reheated and the process repeated two or three times, finally heating and quenching in water. This has the effect of producing a thin, glass-hard skin and is suitable for many purposes, the main advantage lying in the fact that the operation is a quick one. If a deeper case is required the work is packed in steel or iron boxes surrounded by a carbonaceous material, such as charcoal specially prepared for carburising steel, the lid of the box being sealed with fireclay to exclude the entry of air. The box is then maintained in the muffle at a temperature of 900° C. for a period of from four to ten hours, according to the depth of penetration required. If the work is then removed in the heated condition and quenched the parts are surface hardened. If a specimen so treated is broken the depth of penetration of the case shows in the form of a fine-grained ring of metal surrounding a more or less coarse-grained core. A refinement which normalises the core consists of allowing the box to cool down, without unpacking, and reheating to 800° C. and quenching the parts and reheating to 750° C. and quenching again. The treatment recommended by the makers of the steel used should be followed to secure the best results.

Another method similar to the foregoing has gained prominence in recent years ; the difference in the process is that gas is passed through the boxes for the same purpose that the solid material is used. See also next section.

Cyanide Hardening.—Small objects are to a great extent treated in a cyanide furnace. Here molten potassium or sodium cyanide is maintained at a certain temperature in a steel pot and the work soaked in it for the requisite period to give the desired depth of case, after which the parts are removed and quenched.

Tempering.—Tempering is carried out where necessary in a bath of oil at the required temperature. Smaller parts which may need to be tempered by visual means are polished and reheated on a hotplate or in a bath of hot silver-sand. Where sand is employed the temperature of the work may be more easily controlled and the tempering localised more readily than with a hotplate.

OXIDISING ALUMINIUM

Anodic oxidisation of aluminium can be successfully carried out by the following methods :

Chromic-acid Method.—Three per cent. solution of chromic acid as the electrolyte. A carbon rod or a strip of stainless steel (the latter is preferable) as the cathode. The bath should be maintained at a temperature of 45° C., and for the first 15 minutes the voltage of the current is steadily raised to 40 volts, where it is maintained for 30 minutes. During the following 5 minutes it is raised to 50 volts, and kept at this voltage for a further 5 minutes.

Sulphuric-acid Process.—In this process a dilute solution of sulphuric acid forms the electrolyte and a strip of lead forms the cathode. The electrolysis is conducted at room temperature, and a steady current of from 10 to 20 amps. is passed for 30 minutes.

In order to obtain the best oxide films on aluminium, it is essential that the metal should be well cleaned previously, especially when it is intended to colour the oxide film. This dyeing process should take place immediately the oxide film has been deposited. Remove the metal from the oxidising bath, wash it well, and immerse it in a 2 per cent. dye solution in the cold. For half an hour gradually raise the temperature of the dye bath to boiling-point, maintaining it at that temperature for a quarter of an hour, and finally wash the dyed metal coating in warm water. Any basic dyestuff may be used for the dyeing of oxide films prepared as above.

CASE HARDENING

Case hardening is an effective method of preventing undue wear on mild-steel surfaces which are moving in contact with each other.

The principle involved is the introduction of carbon into the surface of the metal. It is the carbon component in steel which differentiates it from iron; steel is, indeed, iron with a large percentage of carbon. It is the carbon which enables cast and tool steel to be hardened by heating and suddenly cooling. Tool steel has a high percentage of carbon. Mild steel (such as Bessemer) and wrought iron have little carbon, and these cannot be hardened except by introducing carbon afterwards, and then only the surface for a certain depth (dependent on the nature and length of the process) can be hardened.

The advantage of case hardening is that, while the surface can be hardened to glass hardness, the bulk or core of the piece remains malleable, so that we can have external hardness where we want it without the brittleness which makes hardened cast steel dangerous in many cases.

Mild Steel.—Case hardening of mild steel is used in the case of the bracket spindles, cones, and cups of bicycle ball-bearings.

A steel with as low as 0·1 to 0·2 per cent. of carbon will not harden, but it can be case hardened by heating it in contact with carbonaceous material in an iron box or a fireclay crucible in a hot fire and sealed against the atmosphere. The carbonising material may be any animal carbon, such as ground bone, charred leather, or other simple form of animal charcoal. The cuttings from horses' hoofs at the forge make excellent case-hardening material.

Wood charcoal, soaked in an aqueous solution of sodium carbonate and dried and powdered, makes a good case-hardening compound. There are on the market some special preparations of carbon which have the advantage that they are always the same, and once the time and temperature suitable for any job have been ascertained by usage, the effects can be guaranteed again, because the compound will be the same. This is not always so when bone, leather, etc., are used.

Grinding.—A piece can be case hardened after machining and finishing—grinding, etc., and this is where the process is useful to the mechanic. He can make his part to size and harden afterwards. Other methods require grinding to truth after hardening—an expensive process. Grinding can, of course, be used if a very fine accuracy demands it, but it must be remem-

bered that if the depth of case is not great, then the job will be spoilt.

Articles to be case hardened are packed, in contact with the carbon substance, in cast-iron, wrought-iron, or fireclay boxes. A piece of good-bore steam pipe with a cap screwed on each end makes an excellent case-hardening box for small pieces. The part or parts to be cased are packed in the box or tube, so that they are entirely surrounded by the carbon element and do not touch each other or the walls of the box or tube. There should be a good layer of the carbon over every part. If a box is used, it should be sealed (luted) with fireclay at the joint of the lid or other covering, so as to exclude the air. It should be brought gradually to a good yellow heat in a coke hearth with a gas blowpipe fixed to blow upon it at a regular heat and keep it at that. A temperature of 1,700° is enough, but since the amateur will have no means of measuring this, it may be said that a good yellow glow all round the receptacle will indicate a heat which will do the job. The time required will depend on the bulk of the pieces and the depth of case required.

For small parts, such as my readers may wish to case, an hour or two would be enough, and would give a depth of carbon case of somewhere near $\frac{1}{32}$ in.

If a gas muffle furnace is available, it should be used; but the ordinary gas blowpipe, if it can be supplied with air by a fan electrically driven, is the best medium for getting the heat required.

If a closed coke stove with a long chimney is available, enough heat can be obtained by carefully regulating the draught, and charcoal will give, in such a stove, even greater temperature than coke.

A test piece should be put in with the work—any piece of the average size of the others, and which may be broken for test afterwards, so that if the case is not deep enough the process can be continued, will be suitable. To test for depth of case let the piece cool down, then heat to a full yellow heat, and plunge into clean, cold salt water; next break the piece or grind an end so that the fracture or ground surface shows the hardened part, and the depth will be revealed.

If a part of the surface requires to be left soft, it should be covered with a coating of fireclay, so that it cannot come in contact with the carbon material, and will therefore not absorb the carbon into itself. But it must be ascertained that the clay adheres to the surface, and that it is quite dry before putting the piece in the box.

In some cases a part which is required to be soft is made of bigger diameter, and then, after the first cooling, it is turned off while the whole is soft and before the heating and quenching which harden the carbonised case.

A Case-hardening Compound.—Yellow prussiate of potash and an equal amount of common salt will make a good case-hardening compound for thin-surface hardening in the open fire or by blowpipe.

The part to be heated is blown to a full yellow colour and the compound sprinkled on. It will fuse and adhere to and run round the metal, and the process should be continued, keeping the heat up and continually applying the powder and allowing it to melt and run round the job. Then, while at full heat, the part is quenched as rapidly as possible in a good volume of clean, cold salt water.

The same method is used when case hardening with the patent "Kasenit" compound. It can be used in the brazing hearth, with a gas blowpipe heating the part to a full yellow heat and melting the "Kasenit" powder on and letting it soak into the metal by repeated applications.

PLASTIC WOOD

Plastic wood is sold with a thin liquid; this is poured on to the plastic wood if it is setting too quickly. Softening fluid should also be used for cleaning any surface to which you desire to stick plastic wood.

If you are covering any large surface, first moisten it by rubbing well with the softening fluid or plastic wood made wet with softening fluid. It is important to carry out this preliminary.

Plastic wood should be applied in thin layers, and each layer allowed to harden before the application of the succeeding layer; in other words, if you wish to fix a thick piece of plastic wood, build it up layer by layer so that it is properly dry and hard right through. This helps to moisten the surface with the solvent contained in the plastic wood and ensures a good grip. Plastic wood shrinks very slightly when it is hard, and this is an additional reason for applying it in thin layers if you wish to stick up any holes.

CHEMICAL COLOURING OF METALS

The art of metal colouring is as old as the proverbial hills. The ancient Egyptians coloured many of their metals by chemical processes, some of which are well recognised, others of which are nowadays unknown. Indeed, if a metal is left alone for a sufficient length of time, it invariably tends to colour itself. Thus copper, for instance, will either turn green or brown according to the conditions under which it has been exposed. Zinc and lead will usually acquire a whitish appearance, iron, of course, will turn brick-red in hue, whilst even gold itself will, under some conditions, acquire a deeper and mellower coloration.

The colouring of metals by chemical means is usually termed "bronzing," although, strictly speaking, such a term should only be applied to the browning of metals. If, however, we turn iron blue or copper green, we usually refer to the "bronzing" of the metal.

Not infrequently, the home mechanic, after completing a piece of metalwork, feels the desire to "bronze" or colour his metal object some definite hue and shade. Usually, in the case of the common metals and alloys, this object is not difficult to fulfil.

Polishing and Cleaning.—It is of the greatest importance that all metal objects selected for chemical colouring be perfectly clean. The object should first be polished. Then it should be "degreased" by swabbing it over with methylated spirit or some other grease solvent. Finally, it may be advisable to dip the metal object in a bath of warm dilute hydrochloric acid (spirits of salts) for a minute or two in order to scour it thoroughly. After this treatment, the object is rinsed in warm water, and is then ready for "bronzing."

If a metal object is not scrupulously clean, its subsequent colouring will very frequently be patchy and uneven. Also, the colouring may not be permanent. Hence, it will be clear that a thorough cleaning of the metal object before "bronzing" or colouring is an absolute essential to the success of whatever process may be used, and in all the instructions for chemical colouring given in this section, it will be assumed that the metal object undergoing the process has previously been thoroughly cleansed and, indeed, scoured.

A Dead-black Surface.—Most common metals can be given a dead-black surface coloration very readily by chemical means. For instrument work, such a coloration is very useful and often, indeed, a necessity. The black colour, unlike many of the

painted-on lacquers, does not flake off or chip away. Brass and copper articles can be blackened by immersion for a few minutes in the following liquid:

Copper nitrate	1 oz.
Water .	3 oz.

A small quantity of silver nitrate dissolved in the above solution is said to improve the black coloration produced upon the metal, but its employment is by no means essential.

Copper (but not brass) articles may be made to acquire a slightly shiny black surface by immersion in the following solution:

Ammonium sulphite (Liver of sulphur) . .	1 part
Water	4 parts

Brass articles take upon themselves a steely-grey colour in this solution.

By immersing iron articles in a solution of photographers' "hypo," they are given a blue-black colour, particularly if a little lead acetate or nitrate is dissolved in the hypo. Silver immersed in sodium-sulphide solution turns almost black, while a black colour on zinc can be obtained by immersing it in a solution of antimony chloride.

A pleasant grey colour is produced on iron by boiling it for half an hour in a weak solution of iron phosphate. This process is akin to that of "coslettisation," a thin film of iron phosphate and oxide being formed on the surface of the metal.

Fig. 263.—A sheet of brass partly blackened by means of the chemical method described.

In order to colour brass or copper a variety of shades ending in black, the metals should be immersed in a very dilute solution of ammonium or sodium sulphide. Brass, for instance, placed in an extremely dilute solution of either of these sulphides will acquire a golden appearance, whilst copper, in the same solution, will be reddened. By making these sulphide colouring

solutions stronger or by allowing a longer time for them to act upon the metal, the mechanic will find that he can get almost any yellow, red, brown, or black colour he desires on these metals.

Steel articles can be " blued " simply by passing them through a

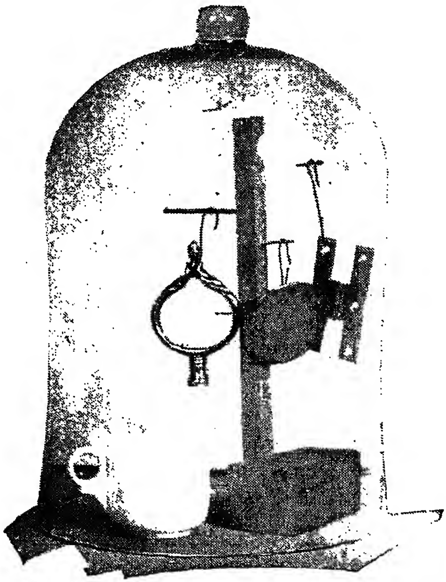


Fig. 264.—Copper and brass objects moistened with vinegar and suspended in an atmosphere containing carbon dioxide gas evolved from a soda solution contained in the cup to give a green patina.

flame. Better still, they may be blued by boiling them for a short time in a strong solution of hypo containing a little lead nitrate.

Antique Effects.—The production of antique effects on articles of brass and copper will be of interest to many readers, since by careful working, beautiful effects of these metals can be obtained fairly readily. The green or brown coloration which an article of brass or copper usually acquires by age and from exposure to the elements is termed a " patina," the word signifying an encrustation. Copper, bronze, and brass patinas can be divided into two varieties, namely, green and brown. The latter

is the easier to imitate by chemical means. If, for instance, an article of copper is dipped in a dilute solution of sodium sulphide, it will instantly acquire a brown patina, the exact shade and depth of the coloration being dependent upon the strength of the sulphide solution. Brass acquires a good patina of the brownish variety when it is heated in a paste made of sulphur and lime.

The green patina which is often seen on brass or copper articles of great age, and which is often very beautiful in appearance, consists, for the most part, of a layer of copper carbonate. We may obtain such a patina on brass and copper articles by burying them in damp earth for a considerable period. Such a process, however, is a slow and an uncertain one.

Green Patina.—An excellent green patina can be given to copper and brass objects by suspending them from some improvised wooden stand and then placing them in an airtight container. Within the container is placed, also, a small vessel containing some ordinary washing soda or bicarbonate of soda, together with a little water. The metal articles are brushed over with strong vinegar, or, better still, with dilute acetic acid, and a little of the acid is poured into the soda-containing vessel, the container then being immediately closed up. The carbon-dioxide gas evolved from the soda-acid mixture will react with the acetic acid on the metal articles, and gradually the latter will acquire a yellow-green coloration and a hard shiny surface.

The operations mentioned in the above paragraph should be repeated every alternate day until the metal articles have been sufficiently coloured, a task which will occupy about two or three weeks.

A quicker method of obtaining a green colour upon brass or copper articles consists in painting them over daily with the following solution:

Copper carbonate	3 parts
Sal-ammoniac	1 part
Common salt	1 part
Copper acetate	1 part
Cream of tartar	1 part
Strong vinegar	8 parts

This solution gives a blue-green coloration which takes about four complete days to develop.

Quite a good yellow-green coloration may be obtained on copper and brass (particularly the latter) articles by brushing them over daily with a mixture of vinegar, common salt, and ordinary sugar.

Note that for the production of these antique green colorations

the metals must not be immersed in the solutions, but merely brushed over with them.

Dulled Aluminium.—The silvery appearance of aluminium is not always desirable. It may, however, be permanently and uniformly dulled by dipping the metal in a hot, moderately strong solution of caustic soda (sodium hydroxide) for a few seconds. The metal will thereafter have a matt appearance. If aluminium so treated is immediately rinsed in warm water and then immersed in a hot solution of an aniline dye, the aluminium surface will take up a little of the dyestuff, and will become permanently tinted. This constitutes an imitation of the now well-known process of "anodising" aluminium and the subsequent "dyeing" of the metal.

By immersing zinc in a hot solution of ammonium molybdate containing a little free ammonia, a deposit of metallic molybdenum will be obtained on the surface of the zinc. This "molybdenum-plated" zinc has a very fine colour, ranging from an iridescent golden yellow to a steely brown. Aluminium articles can be made to acquire a dusky hue by the same process.

What is known as "oxidised silver" is simply silver which has been immersed in a weak solution of liver of sulphur (potassium sulphide) containing a little ammonia. Very weak solutions produce the best results, for in strong solutions the silver is merely blackened.

Similarly, nickel-plated articles may be "oxidised" by immersion for a few seconds in the above solution, in which they usually acquire a dark golden tint.

Brass articles may be made to acquire an extraordinary series of colorations ranging from pale gold to pink and pale blue simply by immersing them in a solution containing half an ounce each of lead acetate and "hypo" (sodium hyposulphite) to the pint of water.

Permanent Coloration.—It is difficult to get good permanent colorations on tin objects. If, however, a sheet of tin is heated to near its melting-point and is then suddenly plunged into the following solution, nitric acid, 1 part, sulphuric acid, 10 parts, water, 89 parts, the surface of the metal will acquire a very beautiful crystalline appearance to which the term *moiré metallique* (watered metal) has been applied.

Metal articles which have been chemically coloured should invariably be well rinsed in warm water and then dried in warm sawdust before a fire. Afterwards their surface appearance may be heightened and improved by rubbing them over with a soft polishing cloth charged with a little light oil.

ELECTRO-PLATING

Electro-plating on a small scale is a simple process which can be carried out by any mechanic. A solution of some salt of the metal which it is desired to deposit is placed in a suitably shaped container, across the top of which is placed a pair of (sometimes three) metal rods. From one of these rods the article to be plated is suspended by means of a piece of wire, while a plate of the same metal as that in the solution is suspended from the other. If an electric battery is then connected to the two rods, so that the positive terminal is connected to the plate and the negative to the article to be plated, then the chemical action caused by the passage of the current through the solution deposits a coating of the metal on the article.

Copper-plating.—As an experiment, let it be supposed that it is desired to copper-plate a small object. Make up a solution of copper sulphate in the proportion of 1 lb. of sulphate to half a gallon of water. Add 4 oz. of sulphuric acid to the solution and suspend the object from the negative rod. A small plate of copper must then be suspended from the other rod and a 4-volt battery connected.

The passage of the current through the solution breaks up the copper sulphate into pure copper and sulphuric acid and deposits the copper on the object, which, within a few minutes, becomes coated with a "blush" of copper. The coating of copper becomes thicker and thicker as long as the current is permitted to flow.

The sulphuric acid which is formed by the decomposition of the copper sulphate attacks the copper plate and combines with it to form fresh copper sulphate. In this manner the composition of the solution remains unaltered throughout the process, but, of course, the copper plate is gradually eaten away.

It is not in the least necessary that the copper plate, or "anode" as it is termed, should be pure copper, because any impurities will be precipitated to the bottom of the solution as sludge, only pure copper being deposited on the spoon.

In order to deposit nickel on the object, we should require to use a nickel solution and a nickel anode; to deposit silver we should use a silver salt and a silver anode, and so on.

Cleaning Process.—It is very important that the object to be plated should be thoroughly cleaned before the plating process, as otherwise the plating will not be durable, and will not adhere firmly. Cleanliness in the ordinary domestic sense is not sufficient—the article must be absolutely and chemically clean.

Some idea of the care required in cleaning may be gained from the fact that if the article is touched by hand before plating, the coating will not adhere to those parts which have been touched.

Commercial electro-plating is a more complicated process than the simple one outlined above, although the principle is identical. The process is complicated by the number of cleaning and washing baths through which the article must pass if the plating is to be sound and a satisfactory job. First of all, the article must be mechanically cleaned, either by emery or by sand-blasting. It is then cleaned by immersion in various acid or alkaline solutions, according to the particular metal.

If the article is required to have a highly polished surface after plating, it must be highly polished before any attempt is made to plate it, because it is most difficult to get a really good finish if the plating is done on an unpolished base, and if the polishing is left until afterwards. Commercially the polishing is accomplished by holding the article against a rapidly revolving buff (see "Polishing"), made of many thicknesses of cotton cloth. The buffs receive frequent applications of polishing compositions, which generally consist of a thick grease mixed with Tripoli, emery, or rouge, according to the nature of the metals and the degree of polish required.

Removing Grease.—In order to remove any grease on the surface the article passes through a hot potash bath which is worked at about 200° F. This bath converts any animal or vegetable fats which may be on the surface into soap, which rises to the surface. After being washed in cold water, the article is ready for the next bath, the constitution of which depends on the plating process to be used.

Nickel-plating is probably the most important commercial process, and to illustrate the general practice of commercial electro-plating the nickel process will be described in detail.

Where the quantity of plating to be carried out is small, the articles are usually transferred from one bath to the other by hand, but where a very large number of similar objects require to be plated, as is usually the case in a commercial works, then large automatic machines are used to facilitate mass production. The automatic plant has the advantage that all operations are correctly carried out, with consequent uniformity in the thickness of the deposit and improved quality of plating.

The various vats are generally placed in line, one behind the other in their proper sequence. Conveyor chains are arranged to move slowly along the line of vats, the articles to be plated being suspended from cross-rods.

The suspended articles pass successively through all the preparatory cleaning and swilling vats before entering the plating vat, and they are then finally washed after plating.

At the end of each vat the articles are lifted automatically by an auxiliary chain, carried forward, and deposited again in the next vat. The various vats are designed to allow the articles to remain in a particular vat for a predetermined time, which cannot be altered without altering the plant.

Various Plating Solutions.—A commercial nickel-plating plant comprises the following processes :

Vat No. 1.—Degreasing. After the articles have been mechanically cleaned and polished, they are chemically cleaned, in a hot, alkaline solution, of all grease.

Vat No. 2.—Cold-water swill.

Vat No. 3.—Cyanide dip. They then pass through a cyanide bath consisting of 8 oz. of potassium cyanide to 1 gallon of water, to remove any stains caused by the potash solutions and to give a final clean.

Vat No. 4.—Another wash in cold water.

Vat No. 5.—Acid dip. They then enter an acid bath, usually consisting of dilute sulphuric acid, to remove all traces of cleaning solutions and to leave the articles absolutely clean and bright.

Vat No. 6.—A further wash in cold water.

Vat No. 7.—Electro-plating. In the case of nickel-plating, this bath consists of a hot solution of nickel sulphate, nickel chloride, boric acid, and water. The solution is kept agitated by means of compressed air, and the articles remain in the bath until they have acquired the correct thickness of deposit.

Vat No. 8.—Wash in cold water.

Vat No. 9.—Wash in hot water.

The articles are then dried and repolished according to the finish required.

While the usual object of electro-plating is to protect the base metal from corrosion, and to increase the decorative appearance, these are by no means the only uses.

One very important process is for the "building up" of undersize or worn metal parts. In engineering work it sometimes happens that some expensive machined part may prove to be slightly undersize, or a bearing may become worn through continual use. Until recent years, such a part would have had to be scrapped, but to-day it may be built up to the correct size by properly controlled nickel-plating methods. More frequently it is built up oversize, and then machined down to the correct size. In ordinary electro-plating the thickness of the plating is

only about 0·001 in., but in this special repair work the thickness may be as much as a quarter of an inch.

Chromium-plating.—Chromium owes its remarkable stainless qualities to the formation of an extremely thin, invisible film of oxide over the surface, as the result of which the metal loses its chemical activity. It becomes non-reactive, and in this condition it resists to a remarkable degree the corroding agencies which would otherwise rapidly result in tarnish. Chromium is an intensely hard metal; in fact, it may be deposited in such a hard state that it will easily cut glass. Its wear-resisting qualities are consequently excellent.

Unfortunately, chromium cannot be deposited directly upon any of the common base metals, as it forms a powerful electric coupling in the presence of any moisture which results in the oxidisation of the underlying metals. The chromium layer is then forced off in the form of tiny flakes. The electrical action between nickel and chromium, however, is very much less than between chromium and any other common metal, and consequently a thick layer of nickel is invariably deposited before the chromium. The nickel is a protection for the base metal, while the chromium protects the nickel and prevents oxidisation or tarnishing.

It must be mentioned that poisonous fumes are evolved during the process, and the work should, therefore, be done out of doors.

The following formulæ give the solutions most frequently used in the actual plating bath:

Copper-plating:

Copper sulphate	2 lb.
Sulphuric acid	8 oz.
Water	1 gallon

Nickel-plating:

Nickel sulphate	2 lb.
Nickel chloride	2 oz.
Boric acid	4 oz.
Water	1 gallon

Chromium-plating:

Chromic acid	$2\frac{1}{2}$ lb.
Sulphuric acid	$\frac{1}{2}$ oz.
Water	1 gallon

Silver-plating:

Silver cyanide	5 oz.
Sodium cyanide	$5\frac{1}{2}$ oz.
Water	1 gallon.

Rhodium-plating.—Rhodium as a plating metal is of very recent date, yet, owing to the excellent results obtained by the process, rhodium plating has achieved a well-deserved popularity for decorative purposes.

Rhodium is a member of the platinum group of metals. It is, of course, a rare and expensive metal, but, fortunately, only a small quantity of rhodium salt is required for plating purposes, and, after the rhodium-plating bath has once been set up, its actual running costs are very low.

Rhodium is almost invariably plated on silver-plate or on sterling-silver articles. The metal is nearly as white as silver and is practically indistinguishable from the latter. It is an absolutely untarnishable metal, so that a rhodium-plated article will, unlike a silver or a silver-plated object, remain bright indefinitely.

An effective rhodium-plating bath may be made up according to the following formula:

Rhodium sulphate	0·25	gramme.
Ammonium sulphate (pure) . .	8·0	grammes.
Sulphuric acid (conc.) . . .	16·0	grammes.
Water	250·0	c.c.

This bath should be used at a temperature of 50° C. The anode should comprise a carbon red, or, better still, a thin strip of platinum, whilst the cathode consists of the silver or silver-plated article which is to be rhodium-plated.

A small battery of 2 volts should be used with the bath, the "current density" (i.e. the measurement of the current passing through a given area of cathode surface) being about 60–70 amps. per square foot of surface to be plated. Thus it will be seen that a fairly heavy current at low voltage is required.

The current should be passed for from 20 to 30 seconds. This will give a very close-grained deposit of metallic rhodium on the silver article, after which the latter should be withdrawn from the bath, carefully drained, well washed, and finally dried and subjected to a light polishing. The rhodium-containing electrolyte must be contained in a porcelain, glass, or enamelled vessel and not in a metallic one.

HEAT-RESISTING CEMENT

Mix up quite quickly 8 parts of pyrolusite crystals (manganese dioxide) with 10 parts of zinc oxide and 2 parts of waterglass (silicate of soda, egg preservative). It is very rapid setting, and when once fused, forms a glass-like mass of great adhesive power.

CHEMICAL PLATING

Quite a number of metals can be plated successfully by chemical means alone, and, apart from the interest attached to such processes, these purely chemical methods of plating can sometimes serve a useful purpose for small-scale work.

The very simplest chemical plating consists in the deposition of a layer of copper on an iron or steel article which is immersed in a bath of copper sulphate solution. The steel or iron article must be scrupulously clean and, preferably, its surface should be bright and polished. Do not have the copper sulphate solution too strong. A moderately weak solution is sufficient, for the copper deposited from such a solution will adhere much better to the steel object.

Some consider that more effective copper plating may be obtained by immersing the iron or steel articles in a bath consisting of equal volumes of moderately weak solutions of copper sulphate and cream of tartar. This bath precipitates the copper in a more golden-coloured form, but it does not work any better than the former simpler bath.

Zinc articles can be copper-plated in the following manner:

Mix equal volumes of fairly weak solutions of copper sulphate and sal-ammoniac (ammonium chloride)—the exact strength of the solutions, as in most of these chemical plating liquids, is immaterial. Clean and polish the zinc surface and then brush the above solution over it with a soft brush. A fine film of copper will be deposited upon the zinc. Do not use too much of the solution otherwise the copper deposit will become flaky and drop off. Be content to employ the minimum amount of solution, wiping away all surplus solution after it has acted upon the zinc for a minute or two. This process can be repeated several times, thereby building up a fairly thick layer of copper upon the zinc.

Imitation Silvering.—What I may term "imitation silvering" is very easily accomplished. There are two good methods of effecting this result, both of which are very easy to apply. The first of these we will call the "dry method." It gives on copper, brass, iron, steel, and other metals a very fine silvery film, which, in the case of copper and brass, may be deposited so thinly that it only just modifies the characteristic colour of the underlying metal.

To carry out this "silvering" method, adopt the following procedure. Place a globule of mercury about the size of a pea in

a mortar or other suitable grinding vessel and add also two teaspoonfuls of powdered chalk. Grind the chalk and the mercury together. After about half an hour's grinding, the mercury will have entirely disappeared and the chalk will have acquired a grey colour. We have now prepared the well-known *Hydrargyrun cum Creta* (Mercury-with-Chalk), or "Grey Powder," of the pharmacist and it is this readily although somewhat tediously prepared material which constitutes our "dry silvering" powder.

Moisten the end of a soft rag with a little methylated spirit and then take upon the moistened area of rag a quantity of the "grey powder." Rub this over the *clean* surface of the article to be silvered. Within a few seconds, a thin shimmering silvery film will form on the metal surface, which film can be thickened by continuing the rubbing with a further quantity of the powder.

The "Wet" Method.—The "wet" method of imitation silvering consists in dissolving a few globules of mercury in *strong* nitric acid, using about five times as much acid as mercury. When the mercury has all dissolved, add to the solution three times its volume of water and bottle for use. This "silvering liquid," when rubbed over the surface of clean copper, zinc, brass, and other metals will almost immediately deposit a brilliant silvery film of considerable thickness. Only a small quantity of liquid need be used and thus it need not be made in large amount. Bear in mind the fact that the liquid is *poisonous* and, therefore, that it should be kept under responsible control.

The "silver" film obtained by the above method is, of course, a film of metallic mercury. While being a very brilliant film and a closely adherent one, it is, unfortunately, not a permanent one. A little of the deposited mercury sinks into the body of the underlying metal, but the majority of the mercury deposit actually evaporates off the metal surface, leaving the latter, after the elapse of about two days, in its original unsilvered condition. If, however, we place a very light layer of varnish over the "silvered" metal, the evaporation of the mercury will be stopped and the "silvering" will be more or less permanent. Spirit or celluloid varnish is suitable for this purpose, but it must be perfectly clear and very thin, otherwise it will dull the silvery surface very considerably.

Another silvering solution may be made by dissolving mercury in nitric acid according to the instructions given above, but, instead of diluting it with water, by adding to it an equal volume of a 5 per cent. solution of silver nitrate. This solution, when rubbed over metal surfaces, will deposit an amalgam of mercury

and silver and thus the deposited metal film will be more truly in the nature of a real silver film.

Aluminium Articles.—Liquids or powders containing mercury should not be allowed to come into contact with aluminium articles. If they do, the aluminium article will be ruined, for the mercury will attack the aluminium, causing it to undergo a very peculiar species of rapid oxidisation. It is, indeed, possible to " burn " a hole in a thin sheet of aluminium by dropping one of the above mercury solutions on to it.

The real silvering of metals can be accomplished non-electrically and without much trouble and, in this case, the chemical-plated silver film is more or less permanent.

Dissolve a few unwanted pieces of scrap silver in the minimum amount of warm, moderately dilute nitric acid and, after all the metal has dissolved, add to the solution about an equal bulk of a strong solution of common salt. This will precipitate white silver chloride. The latter is filtered off, dried in a warm oven and bottled for use.

From the above we can make a rubbing paste which, when rubbed over the surface of copper, brass, and other articles, will deposit a film of pure silver. The rubbing paste is composed of 1 part of silver chloride, 2 parts of cream of tartar, 2 parts of common salt, and sufficient water to make the ingredients up into a thickish paste.

The following liquid will also deposit pure silver on metal objects which are immersed in it:

Silver nitrate . . .	3 parts
Caustic soda . . .	3 parts
Water	10–12 parts

The metal articles are immersed for three or four minutes in the above solution and kept on the move all the time. Afterwards they are rinsed in hot water and dried in warm sawdust.

Sensitive to Light.—It is as well to recollect that all liquids and powders containing silver salts are sensitive to light. It is best, therefore, to carry out all work with them in artificial light and, also, to store such preparations in amber-coloured bottles which are kept in the dark. Do not allow silver solutions to come into contact with the skin *in daylight*, otherwise almost indelible black stains will be produced.

Non-electrical gold plating is, naturally, an expensive procedure these days, but provided one can obtain a small scrap of gold, such a process can be carried out very easily.

Dissolve a tiny scrap of gold in a mixture of two parts of con-

centrated hydrochloric acid and one part of concentrated nitric acid, using as little of the acid mixture as possible. This acid mixture is known as *aqua regia*—" Royal Water "—the name having been applied to it for centuries on account of its property of dissolving the " Royal Metal," gold.

When the gold has dissolved, add a few crystals of green iron sulphate (ferrous sulphate) and boil the liquid. This will precipitate all the gold in the pure form as a dark-brown powder, and the copper and other metals admixed with the gold will be left in solution. Filter off the precipitate and redissolve it in the minimum amount of *aqua regia*. A yellow solution will result. This is a solution of pure gold chloride, containing, of course, more or less excess of acids.

Now pour a little of this solution over a small piece of linen rag and afterwards burn the rag over a small saucer, carefully collecting the ash. The latter will comprise principally a mixture of finely divided metallic gold and carbon. Now take a rag moistened with water or methylated spirit, dip one end of it in the above ash and then rub it vigorously upon the polished surface of the article to be gilded. A film of metallic gold will be deposited and it will increase in brilliance with rubbing.

Gilding.—By shaking up pure gold chloride solution with ether, an ethereal solution of gold will be obtained. This acts as a very excellent gilding solution, particularly for iron and steel articles.

It is not possible to deposit chromium by chemical methods alone, nor, for that matter, is the chemical deposition of nickel usually attended with reliable results. If, however, the amateur wishes to try his hand at non-electrical nickel-plating, he may do so as follows :

Mix equal amounts of moderately strong solutions of zinc chloride and nickel sulphate. Place one or two small pieces of clean scrap zinc in this bath and heat it to near boiling-point. Now immerse in the bath the metal objects to be nickelled. After about a quarter of an hour the reaction will be complete and the articles will be covered with a film of nickel. Usually, however, this film tends to flake off. Hence, the amateur should not be too sanguine of the results of this process, for, even when electrically plated, nickel is one of the most difficult of metals to deposit satisfactorily.

We will skip over the chemical methods available for the deposition of platinum, palladium, and iridium, since these metals and their salts are far too costly to be of much interest to the average individual.

Let us, therefore, consider, finally a very simple method of brass-plating, or "brassing," iron and steel objects.

Brass-plating Liquid.—A chemical brass-plating liquid can be made by dissolving in a pint of water approximately half an ounce each of stannous chloride and copper sulphate. Have the solution slightly warm, clear the iron or steel objects thoroughly and then drop them into the solution, stirring them round until they attain the colour desired. Rinse the objects in hot water and dry them in warm sawdust. Zinc articles can be subjected to this process, but usually the deposited metal film flakes away after the objects have been dried, whereas, with steel or iron articles, the film is very adherent.

Density, Specific Heat, Coefficient of Expansion, Melting- and Boiling-points of Metals and Other Substances

Substance.	*Specific Gravity.*	*Density lb. per cubic foot.*	*Specific Heat.*	*Coefficient of Expansion of Volume per degree Fahr.*	*Melting-point in degrees Fahr.*	*Boiling-point in degrees Fahr.*
Aluminium (Cast) . .	2·6	161·7	·212	·000034	1214	3272
Bismuth . .	9·82	613	·031	·000023	520	2588
Copper . .	8·79	545	·092	·000031	1982	4190
Gold . .	19·26	1200	·032	·000025	1946	4060
Lead . .	11·35	708	·031	·000048	621	2777
Mercury . .	13·598	848·7	·033	·000101	−37·7	670
Silver . .	10·474	653	·056	·000033	1716	3571
Tin . .	7·29	452	·056	·000035	449	4127
Zinc . .	7·19	445	·095	·000049	787	1700

The specific heat in the above table is referred to water as unity. The figures in the column are the number of British thermal units required to raise one pound of the substance one degree Fahrenheit.

THE SPRAY METHOD OF COATING SURFACES WITH METAL

The spraying of metals or other surfaces with metal is a skilled operation. Aluminium, gold, lead, nickel, silver, tin, and zinc have been successfully sprayed on to surfaces, while, on account of the rapidity of the process, there is hardly any oxidisation. It is probable that electro-plating on iron, of brass, bronze, copper, silver, and gold, will hold the field for some years to come. For these metals, when sprayed, do not seem to produce a sufficiently homogeneous coating to prevent the iron or steel corroding and rusting when brought into an acid atmosphere, or in contact with electrolytes.

Preparation of the Surface.—Prior to metal-spraying it is necessary to roughen all surfaces; this is done either by sand-blasting or by blasing with steel grit so that a rough mesh-like effect is produced on the metal. Such a fine structure in a way matches the size of the particles of the finely divided metal in the molten spray.

Cleanliness is essential, of course; metals in the finest state of division simply will *not* adhere to any surface unless it is absolutely free from dirt, and the same precautions which have to be taken in electro-plating are likewise important in hot-metal spraying. A deposit appears to be made up of countless granulations formed as each particle rapidly cools. These particles before solidifying become coated with a minute film of oxide, but this does not prevent the entire deposit from holding firmly together by the partial fusion of each semi-fluid particle, the whole coating adhering to the actual metal surface through the minute net-like surface effect of sand-blasting.

The metal in its transit from the blowpipe feed consists of many millions of isolated globules of molten metal, which partially flatten themselves against the surface to be coated as the result of an intense collision or, if we like, through a heavy bombardment somewhere in the neighbourhood of a speed of 12 miles per minute. Each particle has a diameter approximating a hundredth of a millimetre.

Method of Melting.—The fact that a fine wire when placed in the hottest zone of a blowpipe flame becomes white-hot and then molten—forming globules—is the basis of the metal-spray process. If the globules of fluid metal fall into the path of a high-velocity current of gas, they are immediately broken up into a continuous stream or spray of molten metal. A blowpipe,

incorporating a suitable high-pressure gas supply nozzle, forms the spray-metal tool.

According to the metal used for spraying so is the structure of the surface produced. The essential difference between the structure of a casting lies in the fact that in the latter there is an almost continuous layer (upon layer) of fine metal particles separated by the inclusion of imprisoned gases. Whereas, in a sprayed-metal surface, instead of such gas spaces there are minute films of oxide separating each particle. A considerable difference attaches to the close structure produced by the metals of lower melting-point. In this case, the particles are much smaller and form far finer spray than metals like nickel, gold, etc. This fact renders it necessary to give a thicker coating of the higher melting-point metals.

I mentioned that there was a slight oxidation of the molten particles themselves on reaching the metal surface, but this does not apply to the metal wire itself in its passage from the blowpipe flame to the surface. Proof of this is witnessed in the complete freedom from burning of magnesium, of all metals. As in the case of metal-hardening by rapidly bombarding it with blows (or the impingement of steel balls as in the later methods) so in metal-spraying, the film of deposited metal is slightly harder than the same metal when cast, while its density is a little less.

These slight variations make for certain alterations in the working of sprayed-metal articles, such as higher speed and lighter cut when machining, chiefly perhaps to prevent peeling of the particles by cutting directly through them, instead of "cut-shearing" them. Polishing offers no difficulty whatever, the usual methods being used.

Aluminium Spraying.—Of all metals, aluminium probably offers greatest scope in industry, both on account of its durability on exposure and fairly good conductivity. It is notoriously difficult to electro-deposit aluminium—results are so uncertain. I remember, some years ago, when experimenting with chromium-plating, I made use of an aluminium anode and, with an outrageously high voltage around 200, current density of 5 amperes per square foot of article to be plated (cathode), and a concentrated chromic acid bath, I obtained a most satisfactory deposit of aluminium. A spoon, so treated, is still in existence and has been fairly well used for 5 years or so, and I still have some specimens of iron screws and nails, also a small sheet of aluminium-plated brass which, by the way, were not quite so successful as the spoon, but nevertheless somewhat of a curiosity in the way

of accidental plating. The strange thing, too, was the fact that I obtained almost as good results with a voltage of 6, although the film was more or less oxidised and matt. Aluminium, as far as its electro-deposition is concerned, is a most evasive sort of metal; far and away better results apparently have been obtained by the spraying method.

The aluminium film or oxide is remarkably strong and the metal adapts itself admirably for spraying even for large areas and bulky structures. Temperature of working is rather critical; above a certain limit rapid absorption takes place, and as a protective coat the deposit becomes useless. This temperature limit is 970° C.—this being about 310° C. above the melting-point of aluminium. Iron articles which are spray-treated with aluminium form an exceedingly hard alloy with the latter, which then oxidises to form a scale-free coating. Alternate spraying of aluminium and zinc is most advantageous in many instances, successive layers of the two metals producing a most adherent protection.

Tin and Lead Spraying.—The two metals tin and lead adapt themselves to the spraying process, for the former, on account of its feeble reactivity, is ideally suited to the preservation of foodstuffs and is one of the most useful of the common metals. Unfortunately, it seems that sprayed tin requires to be of fairly good thickness considering the rather porous nature of the metal. Most pots, pans, and other culinary utensils need only a light deposit of tin, which is ordinarily too porous, so to overcome this the film is coated with a layer of varnish. The general thickness of tin deposits is about a sixty-fourth of an inch, which is quite considerable and just shows what may be achieved with the metal spray. Deposits of 10/1000 of an inch of the tin coating are also usual and are very protective. It should be remembered that tin is a really beautiful metal and it is almost remarkable that more use is not made of it for ornamental purposes and motor-car fittings, etc. Its price is fairly high, of course; about £230 per ton as compared with copper at £44 per ton.

Lead, principally associated with the definite protection of metals against acid fumes owing to its great acid resistance, requires a limit of deposit thickness for the latter purpose of a sixteenth of an inch.

Nickel and Silver Spraying.—The chief advantage in the spraying of nickel lies in the fact that great areas may be covered; such would be impossible in the electro-plating of the metal. In this manner huge rolls of sheet iron are easily treated, the size of which would absolutely preclude them from entering the largest

plating-vat made. The use of the nickel spray, however, is decidedly limited, far better results being obtained by the electro method on account of the brilliance of the latter deposit. Thus far, therefore, such spraying appeals only to the commercial and bulk handling of large and unwieldy articles and machinery.

In the case of silver, I cannot see that any particular advantage can be claimed over the electro-deposition method, since any thickness may be obtained by the latter process coupled with many pleasing variations from a matt to a bright finish. Some intricate filigree work may, perhaps, be more effectively treated with the molten-spray method than by electro-depositing, but it is doubtful. Generally speaking, the size and nature of articles for silvering adapt them to the plating-vat rather than the spray. One advantage perhaps of the latter might be in the direct application of silver to iron and steel, which do not require to be coppered beforehand as in the case of electro-silvering.

Copper, Brass, and Zinc Spraying.—The remarks which apply to copper also do to brass and bronze, etc. As a protective coat, brass is often applied to iron, as it also is for ornamental purposes, but a certain thickness is essential. Since steel and iron are by far the commonest bases to which copper and brass are applied, the porosity of the latter metals is important to consider; this is partly due to the largeness of the particles of molten metal—repeated layers of brass and copper are needed to give a perfectly homogeneous and close skin. What happens if this is not provided is this: When brought into an acid atmosphere, or alkaline for that matter, and even damp, the under-surface of steel or iron becomes corroded and gradually oxidised, so that the otherwise protective coating of copper or brass peels off. Thickness of deposit alone is not all that must be considered, for the same peeling effect is liable to occur if the article is damaged in any way so that the coat is scratched. Indeed, this is the most important thing to guard against in all coated metals.

Zinc is chiefly used as a coating to iron, and the incorrectly so-termed "galvanising" usually consists in dipping the iron articles in molten zinc. Electro-galvanising is done as well, of course, but on a large scale dipping is the general rule. As a protection, zinc must be pure, and this purity is ensured by using the spray method of application. It particularly commends itself to the treatment of small articles and is an extremely economical process, since the thickness of zinc sufficient to prevent rusting and corrosion need not exceed one five-hundredth of an inch. The thickness of deposit naturally depends upon the

use to which the articles are to be put, for most purposes twice the above thickness being usual for the prevention of atmospheric corrosion. Zinc, it has already been mentioned, is often sprayed in conjunction with aluminium, the effect being an ideal, tenacious deposit.

Gold Spraying.—Porosity, again, is the chief deterrent in the spraying of gold and, since additional thickness would be prohibitive in most cases, the porous nature can only be checked by using suitable varnishes. However, the same remarks here apply as to silver, for both metals are what may be termed "luxury metals," principally being used for ornamental and artistic effect. Sometimes it is necessary to have appliances covered with gold—as in some laboratory apparatus. On steel, the metals gold, silver, copper, and brass appear to be best deposited electrolytically, very little dissatisfaction arising therefrom.

The factor to be taken into consideration in the spraying of metals is the convenience and facility of adhering to the ground-surface. As has been indicated, this is of decided advantage in the case of metals like aluminium, the electro-deposition of which is a difficult process—such a difficulty being removed by spraying. We have chiefly dealt with the spraying of metal upon metal, but it is equally important to understand that certain bodies—wood, plaster, unglazed porcelain, etc., are quite easily treated by spraying. In their case the process seems to be far more convenient than the usually messy pre-electrolytic preparation—treating carbon-disulphide and phosphorus or brushing with graphite—to obtain a good conducting surface. Certainly, metal-spraying holds out great possibilities and is an attractive and fascinating subject.

BLACK FINISH FOR TINPLATE

The most permanent black coloration on tinplate is obtained by brushing it over with a moderately dilute solution of palladium chloride. This results in a bluish-black coloration. Similar treatment (several times repeated) with platinum chloride results in a greyish-black colour.

Dipping the tinplate article in a hot solution of iron chloride gives a brownish-black colour which may be deepened by subsequent oiling of the surface.

A black nickel bath (electrolytic) is suitable for blackening tinplate. Also the arsenic-dip, consisting of a solution of white arsenic in hydrochloric acid, can also be used if its poisonous nature is not objected to.

THE SINE BAR

In many modern tool-rooms associated with the production of machined parts, where a high standard of precision is absolutely necessary, a great amount of overlapping or re-checking occurs. To the unenlightened, also those who have not given the matter sufficient thought, it appears to be time wasted, but to the management and inspection department, who have the results and experience of years laid before them, it proves to be economical. The human brain is always liable to error ; those little "tricks" of omission, that make such a big difference, are the factors that must be continually held in check.

One result of this is the invention and improvement of modern scientific measuring instruments, such as the precision square, the micrometer, the vernier slide gauge, the vernier height gauge, the protractor, and the sine bar. There are many very efficient protractors on the market at present, in nearly every case of American manufacture. Some are just graduated in degrees (°), whilst others, more costly, are divided up into minutes ('), but no matter how expensive and well-finished they y be, there is unfortunately always a chance of minute errors, an accumulation of which make a large error, and this in an angle can so easily occur, increasing by the distance from the axis point, so that it becomes the usual practice in good-class tool-rooms to use a protractor in the primary stages of a job, and the sine bar combined with slip gauges as a final check.

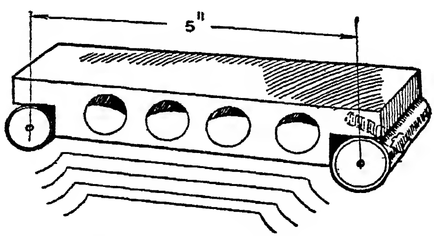


Fig. 265.—A 5-inch sine bar.

Two Standard Lengths.—Standard sine bars are made in two lengths—10 in. and 5 in.; the equivalent measurement to build it up to the angle required is found by multiplying the sine given in engineering text-books by the length of the sine bar being used.

For instance, if one required to set a 5-in. sine bar at 5°, the figure given in the text-book is 0·08715 in., which represents a 1-in. radius ; the amount then required for a 5-in. bar will be 0·43575 in., which is 0·08715 in. multiplied by 5, and for a 10-in. sine bar exactly double the amount will be needed.

In Fig. 265 will be seen an ordinary instrument as made by most of the leading precision tool manufacturers. They are rather expensive, because the process of manufacture is lengthy and necessarily costly. In the majority of cases they are made from high-grade cast steel, roughly machined, afterwards being hardened and tempered, and then rough ground. Owing to the fact that all forms of heat treatment, machining, and especially grinding, set up stress and agitation in the metal, the component parts are hung out in the open air for a period of from three to six months to enable the steel to regain its normal composure. They are then finally ground and lapped, and if supplied by

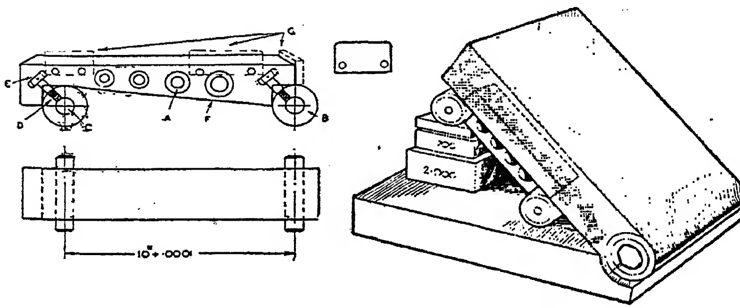


Fig. 266.—An improved sine bar, and an angle plate with sine bar in position.

eminent manufacturers, can be guaranteed to be within an error of 0·0001 in.

Improved Types.—Straying from the standard, the design can be considerably improved, and in many modern tool-rooms this has been accomplished by experience of the requirements. The best design that has come under the writer's notice up to the present is shown in Fig. 266.

A is the bar, with a series of holes F, which are merely for lightening purposes. B are the rollers with a ground hole through the centre C, which will accept a standard mandrel. These rollers are retained in position by a stud D, and nut E drilled to accept a tommy-bar for assembly purposes. The three plates G are to stop the job from sliding off when the bar is set to an angle, and are detachable by removing the screws. This is one of the improvements to this sine bar, and the others are: the roller retaining screws do not go right through as in

most models, which are apt to be unsightly and inconvenient; the hole breaking the surface of the roller. Both sides of the bar are flush with the rollers, which in some cases protrude, making it awkward.

The ground hole through both rollers is a great advantage, as when a mandrel (a slide fit) is in position in each, the bar can be set with the vernier height gauge, the former being packed up with steel strips or small jacks if slip gauges are not available.

Using an Angle Plate.—It often occurs that a job which has to be checked or marked off to an angle is too heavy or dangerous to mount on a sine bar, or probably for the same reason cannot be built up to the angle on a surface plate, and in this case it is usual to first clamp the job on to an adjustable angle plate (made for this special purpose). These angle plates are often fitted with a ring graduated in degrees, which can be adjusted roughly to the required angle before the final adjustment with the sine bar in position (Fig. 266). In very particular cases a sine bar must be built up to the required angle with accurate slip gauges.

Slip Gauges.—A slip gauge is a rectangular piece of hardened steel, the thickness of which is denoted on one of its faces; they can be purchased in sets fitted into cases. The measurements are so arranged that parts can be built up with extreme accuracy equalling almost any dimension to within 0·0001 in. The first commercial gauges were marketed by a firm of precision tool makers—Messrs. Johansson. The process by which they are lapped to such a degree of accuracy and parallelism was, and now is, as far as this firm is concerned, a secret, but at the present time slip gauges are made by several firms all with their own specialised secret processes of manufacture. The composition of sets is in most cases very similar, and one standard set contains 81 pieces, all of different sizes. In the first section are nine slips, the first one being 0·1001 in., and the ninth, 0·1009 in. In the next section there are 49 slips, beginning with 0·101 in. and ending with 0·149 in., then follows another line of 19 slips ranging from 0·050 to 0·950 in. Then there are the four large gauges of 1·000 in., 2·000 in., 3·000 in., 4·000 in. It will be gathered from this explanation that any pack can be built within 0·0001 in. up to the capacity of the set, augmented by the larger-size slips, should it become necessary.

The slip gauges produced by the firm already mentioned are in several grades. The best quality, which are used by many eminent firms as absolutely standard, are guaranteed to within limits of error averaging 2 to 5 parts in a million.

The Comparator.—Slip gauges are in universal use in the majority of tool-rooms at present, not only for setting up a sine bar, but other practices where very fine measurements are necessary—for instance, if a pin projected from a jig or fixture that had to be 2·5005 in. from the base, the usual method of checking this dimension would be on the surface plate with the use of the dial indicator set to the necessary amount of slip gauges and adjusted to zero, and then the point of the indicator passed over the projecting pin in question (Fig. 267).

Very similar to this is the practice of setting up a comparator, a method by which a group of articles is measured with extreme

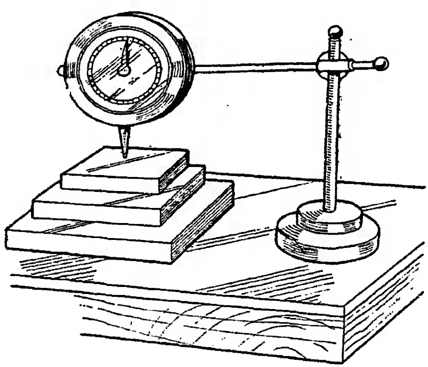


Fig. 267.—A dial indicator set up to slip gauges.

delicacy. This is an instrument with a permanent dial gauge which is adjusted to the required dimension with the aid of slip gauges, usually back to zero. The article requiring to be measured is then passed under the indicator as a comparison to the gauges to which the instrument was previously set. It will be seen from this that a group of articles can be infallibly checked with great rapidity.

Carbide-tipped Tools.—Progress in the machine-tool trades demands cutting tools capable of working at higher and still higher speeds. The introduction of a new form of cutting tool revolutionises the outlook of the machine-tool trade. This happened something over 30 years ago when high-speed steel took the place of carbon steel, and more recently with the introduction of tungsten carbide cutting tools.

Summary of Measuring Ranges and Orders of Accuracy

Dimension to be Measured.	*Instrument.*	*Capacity.*	*Measuring Range.*	*Value of Scale Division.*	*Order of Accuracy.*
Length	Measuring machine—Armstrong-Whitworth	240 in.	2 in.	0·00001	$\frac{\text{Length}}{100{,}000} + 0·00002$
	Newall	72 in.	1 in.	0·00001	,,
	Zeiss	240 in.	240 in.	0·00005	,,
Thickness or outside diameter	Vernier	3–36 in.	Capacity	0·001 in.	0·001 in.
	Micrometer	0–24 in.	1 in.	0·001 in.	0·0001 in.
	Indicating micrometer	0–2 in.	1 in.	0·0001 in.	0·0001 in.
Inside diameter	Vernier	3–36 in.	Capacity	0·001 in.	0·001 in.
	Inside micrometer	1–60 in.	1 in.	0·001 in.	1 in 100,000
Distance between points	Toolmaker's microscope	6 in. × 2 in.	6 in. × 2 in.	0·001 in.	0·0001 in.
Comparison of thickness or outside diameter	Zeiss Orthotest	7 in.	0·004 in.	0·0005 in.	0·00005 in.
	Zeiss Optimëter	7 in.	0·005 in.	0·00005 in.	0·00001 in.
	Zeiss Comparator	4 in.	4 in.	0·00005 in.	$\frac{\text{Length}}{100{,}000} + 0·00004$
	Electrolimit gauge	10 in.	0·00025 to 0·004 in.	$\frac{\text{Range}}{50}$	$\frac{\text{Range}}{50}$
Alignment	Telescope and Collimeter	1,000 in.	0·8 in.	0·01 in.	0·001 in.
Angle	Optical protractor	360 deg.	360 deg.	360 secs.	300 secs.
	Autocollimator	1 deg.	1 deg.	30 secs.	6 secs.
	Zeiss graduated circle	360 deg.	360 deg.	60 secs.	20 secs.
	Zeiss angular division tester	360 deg.	360 deg.	1 sec.	2 secs.
	Angle gauge blocks	90 deg.	90 deg.	1·5 sec.	1 sec.

Tungsten carbide is a non-ferrous alloy, the characteristics of which is intensive hardness. It conveys but little to say that its hardness is exceeded only by the diamond itself. A better indication of its intensive hardness is conveyed by the fact that it will readily drill glass, porcelain, etc., in addition to its growing use for engineering purposes.

Carbide-tipped tools give of their best at high speeds and fine feeds, and to obtain the full benefit of their use the high speeds of which these tools are capable must be exploited to the full.

Thos. Firth and John Brown, Ltd., Sheffield, has, for some years, been developing carbide for tipped tool purposes. Five standard grades are now available.

Grade A is a tough alloy for use where the rigidity usually demanded for carbide tools cannot be obtained.

Grade B is a hardened general-purpose steel for use on cast iron and non-ferrous metals.

Grade C is for use on very hard or abrasive material, vulcanite, porcelain, glass, and chilled iron.

Grade TA is for use in important classes of steel, and a feature of this grade is that although it gives the best result on intensive cutting on good machines it also proves very satisfactory when taking rough, intermittent cuts.

Grade TE is for light, fast, finished machining of steel.

SPEED AND POWER FOR MACHINERY

Circular Ripsaw: 7,000 ft. to 9,000 ft. per minute; horse-power equals the diameter of saw squared and then divided by 40.

Bandsaw: 3,500 ft. per minute; horse-power equals diameter of wheels squared and then divided by 300.

Planer: 3,500 ft. to 10,000 ft. per minute; horse-power equals width of cut divided by 2.

Boring Machine: 375 to 750 revolutions per minute; horse-power equals diameter of hole divided by 2.

Lathe: 900 revolutions per minute; horse-power equals diameter of work divided by 6.

Moulder: 5,000 revolutions per minute; horse-power equals the product of the width and depth of cut in inches.

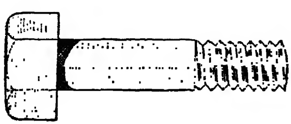
Another suggestion as to the approximate horse-power for circular saws is to provide one brake horse-power for every inch depth of cut required.

BOLTS, NUTS, AND SCREWS

While certain non-standard bolts and screws are encountered occasionally, those used by most manufacturers conform to standard patterns.

Bright Hexagon Bolts.—Bright bolts of this description are commonly made from bright hexagonal mild-steel bar. Such bolts are in general suitable for fixing or holding-down purposes, but even where apparently adaptable, are totally unsuitable for use under conditions where they will be subjected to heavy stresses. The length of the threaded portion is made proportionate to the diameter of the bolt, and is usually equal to twice or three times the diameter, although extra-long bolts have more thread than this. Bolts of this description, in fact all bolts, are fitted with standard nuts. Two distinct standards exist for bolt-head and nut dimensions. Thus, in the British Standard Fine, British Standard small hexagon, or Auto-Whitworth ranges, the widths of the bolt heads, or nuts, across the flats are, in comparison with standard Whitworth bolts, made equal to the next lower size in that range; that is to say, a $\frac{1}{4}$-in. bolt in the B.S.F.

Fig. 268 (below).—A standard $\frac{1}{2}$-in. Whitworth bolt.



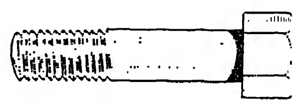


Fig. 269 (above).—A $\frac{1}{2}$-in. British Standard Fine bolt.

range measures 0·445 in. across the flats, whereas in the standard Whitworth range the same material is used for a $\frac{3}{16}$-in. diameter bolt. Fig. 268 shows a standard $\frac{1}{2}$-in. Whitworth bolt, and Fig. 269 $\frac{1}{2}$-in. B.S.F. This fact is worth remembering when buying set spanners, as those normally intended to cover standard Whitworth nut sizes from $\frac{3}{16}$ to $\frac{11}{16}$ in. will also fit standard B.S.F. nuts from $\frac{1}{4}$ to $\frac{3}{4}$ in.

High-tensile Bolts.—Mild-steel bolts are manufactured from steel having a medium tensile strength. As previously stated, such bolts are, under certain conditions, unsatisfactory. In use, a bolt must be regarded as a spring on account of the metal

between the head and the nut, forming the shank of the bolt, being in tension. Now, in the case of a joint between two surfaces, maintained by means of a bolt or bolts, or for that matter studs and nuts, the requirements are that the intervening packing or jointing must be compressed to a certain extent before the joint will hold. Should the packing material be of an unyielding nature, mild-steel bolts will stretch before the jointing has compressed sufficiently to provide a tight joint.

Again, in a connection between a driving and driven member by means of flanged couplings, the friction between the faces of the couplings does much to relieve the bolts from shearing strains. Unless the bolts holding them together will tighten sufficiently without yielding, they will, in use, take the whole load. This means that wear will occur at the junction of the couplings and on the shanks of the bolts, and anything in the nature of a "snatch" may be sufficient to shear the bolts.

The instances already mentioned are typical of the duties best fulfilled by high-tensile bolts, but as a measure of safety they should always be used where everything depends on the bolts. As the name implies, these bolts are made from steel of high tensile strength; that is to say, the material has great physical properties in comparison with mild steel, especially in a condition of tension. They are made in both Whitworth and B.S.F. threads, and are readily distinguishable on account of appropriate markings on the heads and having been heat treated after manufacture.

Coach Bolts.—The familiar shape of the coach bolt illustrated in Fig. 270 is known as a cup, square, bolt and nut, and is made in Whitworth sizes from $\frac{3}{16}$ in. upwards. Their chief uses are in certain forms of body construction, for anchoring body irons to wood framing, and securing the body to the chassis. In all cases the squared portion of the bolt should fit into a corresponding hole in the iron bracket to permit the nut being secured or released easily. Similar bolts are to be had with countersunk heads, and these may be found useful in carrying out body repairs where projecting cup-shaped heads might be objectionable.

Wing bolts are similar to the cup-head bolts. The difference lies in the head, which is larger in diameter and shaped like a mushroom.

Nuts.—Plain hexagon nuts are made in two styles—full and lock. In both the standard Whitworth and B.A. ranges, the full nuts are in thickness made equal to the diameter of the bolt,

and chamfered on one side only. Locknuts, on the other hand, are chamfered on both sides, and in thickness equal a dimension representing two-thirds of the bolt diameter. Similar nuts in the B.S.F. or Auto-Whitworth ranges correspond as regards thickness to the next lower size in the standard Whitworth range. Slotted hexagon and castle nuts are made deeper than standard nuts to compensate against unduly weakening the nut by the pin

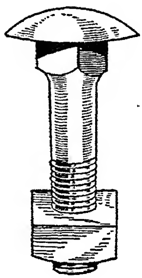


Fig. 270.—Showing a typical coach bolt.

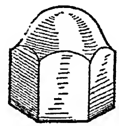


Fig. 271.—This type of nut is known as a cap nut.

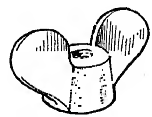


Fig. 272.—A typical wing nut.

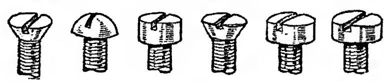


Fig. 273.—Types of screw head. (Left to right): Countersunk, Round, Cheese, Instrument or Raised, Fillister, and Connection.

slots. This point should be borne in mind when making allowances for nuts on bolts that require pinning, otherwise the chances are that there will be insufficient thread left projecting beyond the bottom of the slot to accommodate the split-pin hole. As a general rule the thickness of a slotted nut is equal to the diameter of the bolt, excepting Whitworth and other coarsely threaded nuts, which are made thicker.

The type of nut shown in Fig. 271 is known as cap nut. Besides being used as wheel nuts, this type, in one of the many sizes in which they are manufactured, is suitable as a protection and finish to bolt ends, particularly those used for interior body fittings. Commonly made in brass, they are to be had in self-colour or plated finishes.

Both brass and malleable-iron winged nuts of the shape shown in Fig. 272 are as standard tapped with Whitworth thread in sizes ranging from $\frac{3}{16}$ to $\frac{1}{2}$ in. diameter.

Screws.—All metal thread screws are threaded right up to the head. Standard Whitworth and B.S.F. screws are made in four shapes, namely, hexagon, countersunk, round, and cheese-

head, as shown in Fig. 273. These shapes are also repeated in the B.A. range, which includes such additional head shapes as instrument, fillister, and connection.

Wood screws are to be had in three styles—countersunk, round, and raised head, the latter being similar in shape to those of the instrument screws in the B.A. range. A heavier type of wood screw, known as a coach screw and suitable for certain kinds of body repairs, is seen in Fig. 273A. It will be noticed that the screw is driven by means of a spanner. Wood screws are referred to for size by numbers running from 00 smallest and upwards. Coach screws are referred to by the actual shank diameter.

Measurement and Identification of Screw Threads.—The length of a bolt or screw is the measurement taken from under the head to the end of the thread, excepting in the case of countersunk screws, in which the length is the overall measurement.

The threads in common use are British Standard Whitworth, British Standard Fine, British Standard Pipe, and British Association, these being, of course, the standards of this country. Those of America are United States Standard or Sellers, Society of Automobile Engineers, and American Society of Mechanical Engineers. The International System Metric Thread is the standard of most Continental countries. In the order named, the threads mentioned, in an abbreviated form, are designated as follows: B.S.W. or Whit., B.S.F., B.S.P., B.A., U.S.S., S.A.E., A.S.M.E., and S.I. (See Tables at end of book.)

Whitworth screws or studs are most likely to be used in soft metals, on account of the deep thread afforded by the coarseness of the pitch. B.S.P. threads are used in connection with unions for petrol and oil piping. The nominal diameter of the thread refers to the bore of the piping for which it is suitable, and this practice is followed out in the case of union nuts, which are mostly tapped with this thread. Unions for both $\frac{1}{8}$-in. and $\frac{3}{16}$-in. diameter pipes are tapped $\frac{1}{8}$ B.S.P., although as a warning it should be mentioned that those for $\frac{3}{16}$-in. diameter are sometimes tapped $\frac{7}{8}$-in. diameter $\times$ 19 threads per inch.

B.A. threads are used in substitution for B.S.F. in sizes below $\frac{1}{4}$-in. diameter. These run from No. 0, just under $\frac{1}{4}$-in. diameter, to No. 22, about $\frac{1}{64}$-in. diameter, and are in common use on the items comprising instruments and electrical equipment. In this class of work, screws below No. 10 B.A. are seldom used, and therefore need not be considered.

So far as its application is concerned, the S.A.E. thread may

be likened to B.S.F. and A.S.M.E. to B.A. As with B.A., the diameters are denoted by numbers; No. 0, the smallest, is about $\frac{1}{16}$-in. diameter, and No. 30, just over $\frac{7}{16}$-in. diameter, the largest.

Of the thread systems mentioned, two only employ the same thread formation. These are Whitworth and B.S.F. For purposes of identification, thread formation may be ignored excepting in the case of the U.S.S. thread, which size for size up to $1\frac{1}{2}$-in. diameter follows Whitworth as to pitch, with only one alteration, which is the $\frac{1}{2}$-in. diameter bearing 13 threads per inch. As distinct from Whitworth, the shape of this thread is shallower on account of the angle being 60° and is flat at the root and crest.

Screw-pitch Gauges.—Although screw-pitch gauges form the most convenient method of measuring pitch, such gauges are not absolutely necessary; in fact, a fine rule and a pair of outside

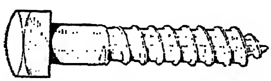


Fig. 273A.—A heavier type of screw, known as the coach screw.

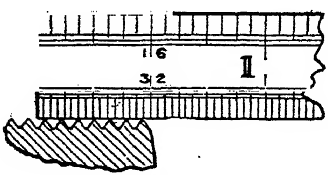


Fig. 274.—How to find the pitch of a thread.

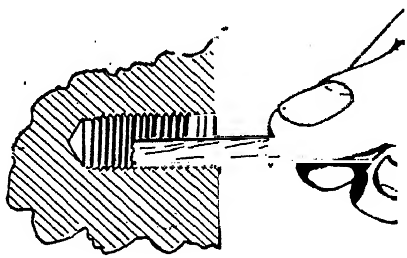
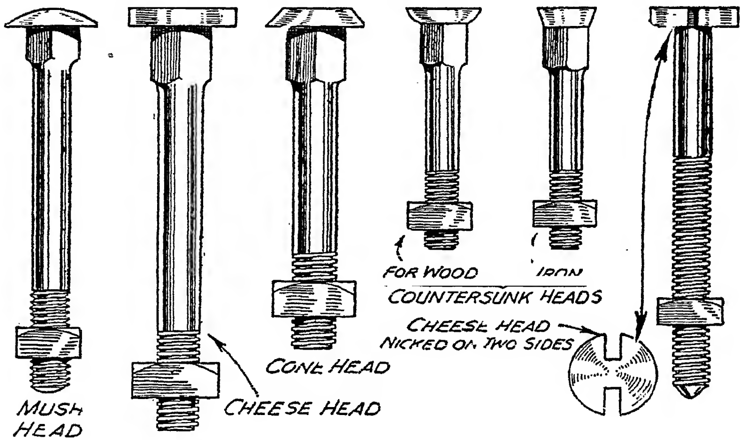


Fig. 275.—A simple method of measuring the pitch of a female thread by impressing the screw thread on a piece of wood.

callipers will give satisfactory results, so far as tools are concerned. For measuring the diameter of coarse threads, the callipers should have broad gauging faces.

After the diameter of the thread has been measured, the pitch is found as shown in Fig. 274, the end of the rule is set opposite to the root of a thread, and the number of complete threads in a given distance counted. In the illustration there are seven complete threads in $\frac{1}{2}$ in., or fourteen threads per inch. Thus, if the diameter is $\frac{5}{8}$ in., the thread would be identified as $\frac{5}{8}$ B.S.F.

It is not always possible to measure the pitch of a female thread directly with a rule, and a simple method of doing so is shown in Fig. 275. A piece of softwood that will pass easily into



Figs. 276 to 281.—Various types of bolt.

the tapped hole is pressed into the thread and the pitch taken from the resultant impression. Smaller sizes can be dealt with by twisting a piece of wood, a little larger in diameter than the core diameter of the screw, into the hole, and unscrewing carefully so as not to damage the shallow thread obtained.

Elements of Screw Threads.—The elements of a screw from the point of view of measurement are the major diameter, minor diameter, effective diameter, adjacent pitch, accumulated pitch, angle of thread, radius of profile at crest, and the radius of profile at the root. The last two are not important, because contact between screw and nut is not necessary at the crest or the root of the thread, and in fact a definite clearance is sometimes provided by adopting a flat-topped crest for the thread of each member. The major diameter of the screw may be measured directly by micrometer, and the minor diameter by means of "go" and "not go" gauges. The measurement of screw threads by the wire system, and by optical projection is dealt with in our companion work "Screw Thread Manual."

PATTERN MAKING FOR CASTINGS

The plastic material in which the moulder takes an impression from the pattern is sand. Not just ordinary sand such as is found on the seashore, but a fine quality which is composed of several ingredients, including loam.

Two iron boxes, each open at top and bottom and which fit accurately together, kept in alignment by means of lugs and dowel pins, are separately filled with sand in a slightly damp condition, and on the parting line between the faces of the boxes the pattern is placed, one half of the pattern being embedded in the sand in one box and the other half in the other box. The sand is well rammed around the pattern, the boxes separated, pattern removed, a groove, termed a runner, formed through which the metal is to be run, and the whole mould is then ready for casting.

Fig. 282 shows a pair of these boxes in section, filled with sand and with four patterns, of different shapes, on the parting line. Fig. 283 is a sketch of the empty boxes in perspective, showing the dowel pins, which ensure their coming back into line, one with the other, after opening.

As no particular part is being dealt with at present, but only the principles of the craft, the four patterns are examples of what can be done in a simple way and what cannot be done without special arrangements in the pattern.

This brings us to the important matters referred to, one of which is that in making a pattern allowance must be made for the fact that the casting, of whatever metal it is to be made, will shrink in cooling, and the pattern will have to be somewhat larger than the required size of the resulting casting. Now, the amount of contraction which takes place depends upon several things: one, the nature of the metal; two, in iron, to some extent upon the quality of the iron; and three, the size and shape of the article. A long, slender rod, weighing, say, half a pound, will shrink more per foot of length than a short, thick rod of the same weight, and a little experience is needed in order to know just how much to allow. Until that experience is gained, it is best to be sure of allowing a sufficient amount. In ordinary soft iron, the contraction will be not less than about $\frac{1}{100}$ in. for each inch of length; thus, if a rod is to have an overall measurement of, say, 10 in., the pattern for it will require to be made $10\frac{1}{10}$ in. long.

Brass has a somewhat greater rate of contraction, and a pattern for such a rod may very well be given a length of rather more than $10\frac{5}{32}$ or $10\frac{1}{8}$ in.

When we come to gunmetal, we find that shrinkage takes place to the extent of $\frac{1}{64}$ in. to the inch, so that for a 10-in. rod the pattern will have to be made at least $10\frac{5}{32}$ in.

Small Castings.—Small castings, in any metal, whose greatest measurement does not exceed, say, $1\frac{1}{2}$ in., need have no allowance for shrinkage, because the moulder will, in order to facilitate the withdrawal of the pattern from the sand, rap it to loosen it. Such rapping has the effect of very slightly enlarging the size of the opening in the sand to a small amount greater than that of the pattern, so making the necessary contraction allowance. Reference has been made to the length only by which a pattern must exceed the measurement required in the casting, but the moulder will understand that not only in length, but in breadth, depth, thickness, and every dimension, this contraction allowance must be made.

In addition to provision for shrinkage, allowance for extra metal must be made on the portions of the castings which are to be filed and machined. Some parts will be finished by just removing the roughness with a file, other parts may not have to be touched, but again, others will be either faced up by filing and scraping, or be turned in the lathe or milled. On portions of, say, small model engines, the allowance for filing need not be more than $\frac{1}{32}$ in.; often, when it is known that the founder to whom the patterns are to be sent works accurately and produces nice smooth castings, $\frac{1}{64}$ in. is often enough for the filed work, with possibly as much as $\frac{1}{16}$ in. for turned portions.

Cast iron enters largely into general engineering work, especially for machinery, and unfortunately it is often found that castings for these are encased in a hard skin, which the turning tool in the lathe will not attack successfully without constant regrinding. The only way to deal with such castings is to take a sufficiently heavy first cut as will get the point of the tool underneath the skin. This, however, involves the removal of a considerable amount of iron, and so such a contingency must be foreseen by the pattern-maker, and a generous allowance made on the tyres and rims, so that the finished wheel will hold up to the required scale diameter.

The next important matter to be borne in mind in preparing a pattern is the question of whether its shape is such that it can be drawn from the sand after ramming. If it is not of simple form having straight lines, as in Fig. 284, or balanced curved lines as shown in Fig. 286, that is to say, if it is undercut in directions at right angles, or approximately right angles, to each other, it will not draw, and the design of the pattern

becomes more complex. The use of prints and cores will have to be resorted to, and the pattern proper will not be carved to the same shape, on all its parts, as that of the required casting.

Suppose we wish for a casting of the form sketched in Fig. 286, where in Fig. 284 the metal object is shown in cross-section and in Fig. 286 in perspective, then it will be obvious that, if we were to make the pattern of exactly this shape inside and out, and embed it in sand, the pattern could not be withdrawn without tearing away that sand which fills the interior at *a*. In other words, the interior sand will not be left in the moulding box, but will come away with the pattern. It will be evident, therefore, that the pattern cannot be made exactly like the casting. So what we have to do is to core out, with a separate block of moulded sand, this recess *a*. Now, the only way to make such a core of a particular shape as this, is to prepare a corebox in which the core sand can be moulded, and, corresponding to a part of this core, a print *b*, upon the pattern.

In Fig. 285 is drawn the pattern with the print referred to and in Fig. 287 one of the faces of the corebox. Fig. 288 is a cross-section through the box at right angles to the faces. From this last sketch it will be seen that the box must be made in two halves, that the moulding recess for the core must be carved from the solid wood, and that the two halves of the box must be accurately dowelled together so that the two faces of the box always come back into correct alignment.

The Corebox.—Obviously, an opening must be left in all such coreboxes through which the moulder can fill the box with sand and ram it in hard. In the box shown in Figs. 285 and 287, the most convenient place—the only place, in fact—where such filling opening will not interfere with the shape of the core is at the bottom. Here the core has a simple flat face, and the moulder, after he has filled the box, will strike off the sand and leave a true face, flush with the bottom of the box. The core, after it is taken from the box, is thoroughly baked, the loamy sand, from which it is made, being of such an adhesive quality that the core can then be handled quite well without risk of its crumbling to pieces.

The moulder will now see that the lower or tapered part of this core, if placed in the recess, in sand or the bottom moulding box, left by the print *b* on the pattern, will allow the complete core to stand in relation to the impress of the whole pattern, in the manner shown in Fig. 289, which is a section of the upper and lower moulding sand with the core in position, and that the space left vacant is of exactly the required shape of the

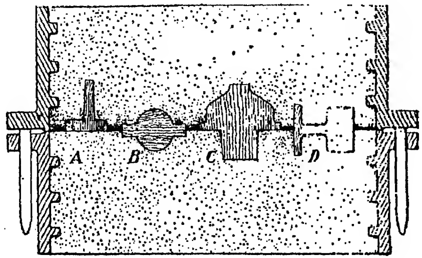


Fig. 282.—Moulding boxes with patterns embedded.

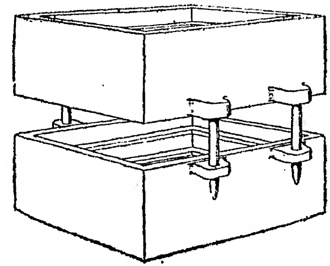


Fig. 283—A pair of moulding boxes, showing locating dowels.

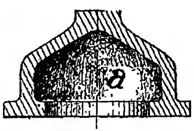


Fig. 284.—Example, in section, of pattern which will not "draw."

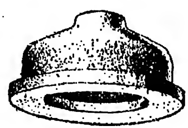


Fig. 286.—Perspective view of example shown in Fig. 284.

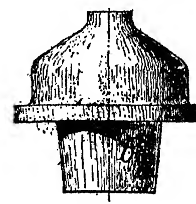


Fig. 285.—Pattern with print for "coring" example shown in Fig. 284.

casting. When the metal is poured into the mould, it will flow around the upper part of the core, which, after the casting has cooled and is removed from the moulding sand, can be crumbled away, thus leaving the required hollow interior to the casting.

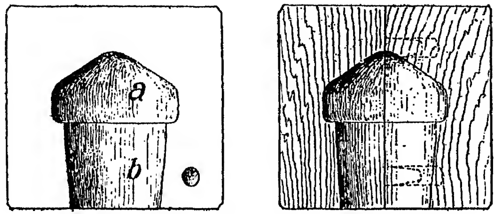
In making such patterns and coreboxes as these, it is of the utmost importance that the print on the pattern and the corresponding portion of the interior of the box must both be of such relative sizes, i.e. diameter and length, that the core which comes from the box can be placed accurately, without tightness or looseness, in the impression left by the print in the sand of the moulding box. On this accuracy will depend the truth of centring of the upper part of the core in the casting.

If the core were a loose fit, the hollow in the casting would, most likely, be found out of centre, whilst on the other hand, if the box is made too large, the shank of the core would not go down into place in the mould.

Actually, the diameter and length of the print on a small pattern should be about $\frac{1}{100}$ in. smaller than the corresponding part of the corebox.

Undercuts.—We will now deal with the kind of cast part which must be cast with undercut portions at right angles one with the other, one or more of which undercuts must be cored out, but not necessarily with a circular core. A pattern for such a casting is indicated on the right-hand side of Fig. 291, the full and correct cross-sectional shape of the casting being as sketched in Fig. 290.

Now, there are two ways in which the pattern for this can be made, and, in consequence, two ways in which it can be moulded. These are shown in Figs. 287 and 288, where the impress of the two patterns and the required cores are shown in the sand. There is not very much to choose between the two methods, as only one corebox will have to be made in either case, since, in B, one box will suffice for the two cores, assuming, of course, that each of the channels is of the same size and length. But there is just one little thing which gives B the advantage over A. It will be seen that the large face of the flanges, marked C, if moulded as at A, will not slide with perfect freedom from the sand when the moulder lifts the pattern after ramming, unless a little taper or draw is formed in the pattern. Such draw on the pattern will, of course, be reproduced in the casting, and as the face will doubtless be required flat and true with the least amount of labour in finishing the casting, the alternative arrangement will perhaps be the better. It will be obvious that, if the method of coring at B is adopted, the pattern will be



Figs. 287 and 288.—*Plan and elevation of corebox.*

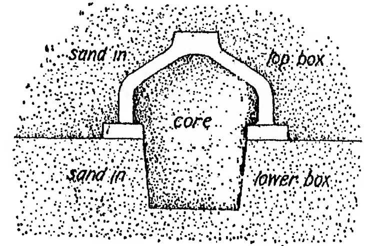


Fig. 289.—*The core in position in the mould.*

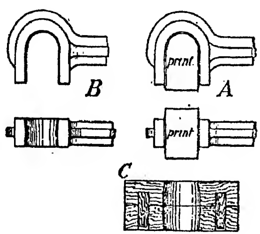


Fig. 292.—*Pattern alternatives for end of connecting rod.*

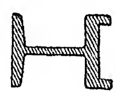


Fig. 290.—*Section of casting.*

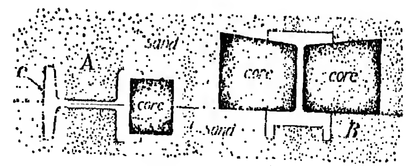


Fig. 291.—*Alternative arrangements of cores.*

made with a large print on each side as shown. The model shown in the drawings is, in this case, quite nondescript, and represents nothing in particular. It is merely designed as an example of how to deal with such objects by methods which have very commonly to be resorted to in many small foundry jobs.

Saving Time on a Job.—A question which the engineer who is preparing his own patterns has very often to decide is: *Which will save me the most time on the job—to make a* corebox to core out a certain simple opening in a casting, or to work up a flat face where, without a core, draw has to be allowed for? And another question: Will the pattern be strong enough to stand the ramming of the sand without a core?

A case in which both of these queries are applicable occurs in the two ends of a connecting rod for a steam engine. Fig. 292 shows how, by two alternative methods, the pattern for it could be made. At A the pattern is made with a solid end and prints on each side for one core to run through; whereas at B the end of the rod is carved with an open end. There is not much difference in the amount of labour required in the two kinds of pattern, and not very much extra in making the corebox, since it will be cut from two flat pieces of board dowelled together and pierced right through, as at C.

When considering the resulting casting from the open pattern, notice that the draw which is necessary in the opening, to ensure its leaving the sand cleanly, involves a considerable quantity of unwanted metal being left to be filed or machined away, besides which the pattern is somewhat weak, and would have a tendency to open out under pressure of ramming; so there can be no question but that the best way will be to core out the opening. In the drawing at C, the dowels are shown glued in one part of the box and tapered, making a nice sliding fit into holes in the other.

One of the most complicated sets of patterns called for in an engine is that for the cylinder of an engine which is of sufficiently large scale to necessitate the coring out of all the ports, both steam and exhaust. Between cylinders for locomotive, marine, or stationary engines, there is little difference in the amount of work involved in making the patterns, though much depends upon the particular design and the degree of faithfulness to which the prototype is copied. Of course, the question as to whether the ports need be cored out depends upon the scale of the model or the size of the cylinder, but it may safely be said that any cylinder above 1-in. bore by, say, 2-in. stroke ought to have cored parts, because only by so coring can the greatest

possible cross-sectional area be given to the steam passages, Drilled ports result in wire drawing of the steam and loss of power.

For the purpose of giving an example of such a set of patterns. I cannot do better than select one for a locomotive having outside cylinders with inside valve chests, but such parts as the slide valves, cylinder covers, glands, pistons, etc., will not be touched upon, since all patterns for these will be of the simple kind, which call for no coreboxes or manipulation on the part of the moulder. The cylinder itself, or one of them only, will be dealt with.

Cylinders.—On full-size steam engines the cylinders are right- and left-handed, the back cover being made smaller than the front end, which is of full diameter; and often there are other things, such as the positions of exhaust ports and steam-inlet facings, which make them of opposite hands. In such cases two sets of patterns have to be prepared, but in models of 1½-in. scale or smaller, the patterns are more often made to do for both cylinders, by simply turning one casting round the opposite way; the end which is the front on, say, the left hand is the back end on the right, and every part is made so that the cylinder is balanced across the centre line. That is what is proposed to be done in the design for patterns here given, it being understood that the principles shown will be equally applicable if two sets of patterns are required to be made for a model which is a more exact copy of some particular full-size engine.

The practice of turning one or two castings the opposite way round for right- and left-hand cylinders includes the possibility of coring out a port, in the cylinder casting itself, to lead the steam from the steam-pipe attachment to the valve chest; so in the design here given, the steam pipe is taken on to the chest itself, so leaving the cylinder free of all pipe-flange fixing, save the exhaust pipe, which will come on the cross-centre line.

An Outside Cylinder.—Fig. 293 is a collection of views, drawn to scale, for such an outside cylinder as that referred to. It is designed for a 1½-in. scale model, but can be adapted for any scale within certain limits of smallness. For instance, it cannot be used below a scale of 1 in. to the foot, because it is impracticable in smaller sizes to core out the ports, and such ports in small cylinders must be drilled out.

In Fig. 293 A is a horizontal section through the cylinder, valve chest, slide valve, and ports. B is a cross-section taken through the centre, i.e. through the exhaust port, with one of the steam ports shown by dotted lines. C is a plan; a view looking down upon the top of the cylinder and showing the exhaust-pipe

attachment studs on the flange and the steam-pipe flange secured to the chest. D is a back-end elevation.

These views of the cylinder complete are given in order that the moulder may understand what has to be arrived at by the peculiar shapes of the patterns, coreboxes, and cores, which will be described and shown in the following sketches.

Look at D and C, Fig. 293, and ignore the piston, cylinder covers, valve chest, etc.; these show that, in order to form the cylinder itself and the mass of metal on the right to which the valve chest is attached, a pattern will be required which will yield in the sand an impression of the exact outside shape of the whole, but it will be obvious that the same pattern cannot give the inside shape. The form of the inside, that is to say of the tubular bore, of the steam ports, or passages, with their double bends, and of the central exhaust port, must be got by means of cores, four in all—one for the cylinder barrel, one for the exhaust port, and one for each of the steam ports.

These cores, after they are made, will have to be supported, and so prints will have to be formed in the main pattern.

Patterns in Two Halves.—For the convenience of the moulder and the sake of the cleanness with which the pattern leaves the sand, it is usual to make such patterns as this—and, in fact, more circular patterns of fair size—in two halves, parting them on the centre line and dowelling them together, just as has been described for coreboxes. This, therefore, will be done in the present case, and in Fig. 294 a view is given at A of the lower half, showing the dowel holes and the positions of the four cores. It is always an advantage, and helps the moulder to understand what he is required to do, if cores are drawn upon one half of such a pattern as this, and painted in with black shellac.

At B, the complete pattern is shown in perspective, and here all the prints are visible, together with the dowels and dowel holes, which, making a nice, easy, sliding fit, without undue looseness, will retain the two halves in alignment.

The view B, Fig. 294, indicates the method of dealing with a projecting flange of the exhaust-pipe facing. A moment's consideration will show that if this flange, in the pattern, were formed solid with the rest of the wood and the pattern embedded in sand, it could not by any means be withdrawn without tearing the sand away; so, to render it possible to remove the pattern and still have a projection in the casting, this projection piece in the pattern is so made that, as the pattern is lifted, it will slide off and be left in the sand. The moulder will then take a pair of tweezers and carefully remove the loose piece, with-

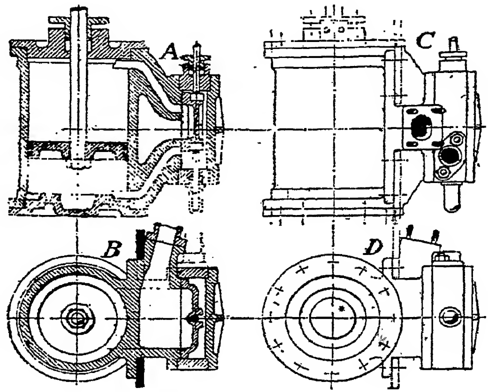


Fig. 293.—*Section of locomotive cylinder.*

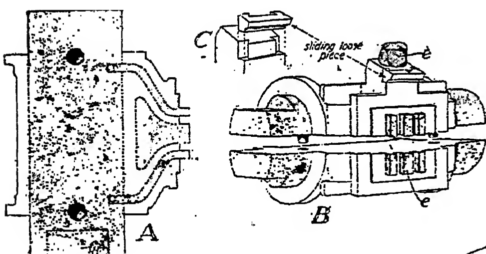


Fig. 294.—*Pattern for locomotive cylinder.*

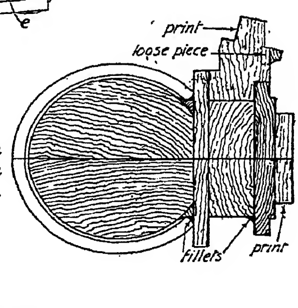


Fig. 295.—*Cross-section through pattern for cylinder.*

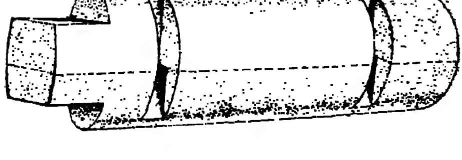


Fig. 296.—*Core for cylinder.*

drawing it in a direction at right angles to that at which the pattern left the sand.

This feature of the loose piece has been specially introduced here in order to give the reader a good example of a practice, and a perfectly sound one, which is quite commonly resorted to in all pattern making for engineering work, both large and small.

In order to secure the loose piece whilst the sand is being rammed, and the pattern handled generally, it is formed with a sliding dovetail, such dovetail being cut in a direction parallel with that in which the pattern will be lifted out of the moulding box. The sketch at C shows the loose piece raised above the dovetail on the main pattern.

The Cores.—Coming now to the cores, and dealing first with that for the exhaust port, we see from B, Fig. 297, that this will have two points of support in the sand, two prints having been provided for it in the pattern, marked *e e* in Fig. 294. The box for forming this core is therefore to be made as in Fig. 297. Here it is seen that the box is made in two halves, and is open at both the points which correspond to the prints. This is done to enable the coremakers to ram from opposite ends. The sketch on the left is a face view of one half of the box, whilst the two middle drawings are cross-sections through the box on different levels, marked A and B respectively. The sketch on the right is a perspective view of the resulting core.

The moulder will arrange this cylinder pattern upside down in the sand and the casting will be made in that position. This exhaust-port core will be the principal reason for doing so, for it will be seen that, if it were moulded right way up, the core, before the top box is replaced, would only be supported by the lower part of the print in the port face. Whilst it is true that a core can be fixed by the use of a special glue or by sprigging, it involves more work than would moulding the other way up; for then the core can rest upon two points: the upper half of the port-face print and the impression of the top print at the exhaust-pipe flange. Consequently, the core will be standing as at E, in Fig. 298, which—the sketch on the left-hand side—is a cross-section through the sand of both boxes showing all of the cores in position.

The Steam Port and Cylinder Cores.—The reference to this figure number brings one to both the steam-port cores and the cylinder core. For the steam-port cores two boxes must be made. Although both ports will be exactly the same shape in the casting, it is unfortunately the case that, in order to afford the cores adequate support, a right hand and a left hand are

required. At their port-face ends they will be carried by the pattern prints, but at the cylinder ends they touch no part of the moulding sand, and must therefore have supports provided for them in the cylinder core, so this cylinder core is shaped as shown in perspective in Fig. 296.

Compare the shape of the core in the corebox at the top right hand of Fig. 298 with the notched openings in Fig. 296, and then refer to the cross-section to the left of Fig. 298. In this latter view the port core P is shown resting in the notch in C, the cylinder core. It will be seen, too, that this notch is the only means of carrying this end of the port core.

When he places the cores in the sand, the moulder will first drop into position the cylinder core and then lower the two port cores. Now, the important thing which will be obvious in connection with the carrying of the free ends of these port cores is that it will matter a great deal just how the cylinder core is placed, since the position of the ports in the casting will depend upon the accuracy of the level of the notches in the cylinder core. So, in order to guard against the possibility of its being either too high or too low, a flat, or two flats, is arranged on the cylinder prints and corresponding flats in the cylinder corebox. The flats on the print are shown in Fig. 295, whilst those on the core are sketched in Fig. 296. The corebox for the cylinder core has not been drawn, but its internal shape will be obvious from Fig. 296 if taken in conjunction with the many other corebox drawings.

Dealing with the construction, it may be said that few patterns, even small ones, are carved from one piece of wood only. If they are perfectly round, as in the case of a cylindrical piece, they will be turned from the solid in the lathe, and finished there. A locomotive-chimney pattern, too, will be turned, the base to fit over the smokebox, being afterwards shaped with the chisel; but such a pattern as that required for the casting illustrated in Fig. 295 will be built up of three pieces bradded and glued together: two pieces for the flanges and one for the web.

When coming to the pattern for the locomotive cylinder, a still greater number of pieces will be called for, in order to save labour in carving; and in a few places, in order to form curves in angles, fillets will be formed, either of glue and plaster or plastic wood (Fig. 295).

The Cylinder Barrel.—This should not be turned and then sawn in two to form the divided pattern, but two pieces of wood should be taken, planed true on two faces, and loose-dowelled together. Each face is then coated with thin glue, the two

glued faces put together with a piece of newspaper between, and clamped up to dry. When the glue is thoroughly dry, the two-piece block is mounted in the lathe and turned to shape. On completion of the turning, the thin blade of, say, an old table knife is driven through the glued joint, with the result that the newspaper will split and the two halves of the pattern come apart. The only thing to guard against is letting the glue soak through the paper; if it were to do so, there might be trouble in parting.

The best plan is to let the glue chill a little on each face, and to use newspaper which is perfectly dry. Should it be thought that there is a risk of rupturing the joint by pressure of the lathe centres, it would be well to put a screw through one half into the other at each end, beyond the limits of the pattern.

Coreboxes may sometimes be built up in the same way as patterns; but it is usually the case that the nature of their internal shape, being in reverse, rules out the possibility, and they can then only be made by carving with bent gouges and chisels, and perhaps wood-carvers' tools. A corebox, such as that for the exhaust-port core shown in Fig. 297, is a case in point. So, also, is the corebox for the cylinder core, Fig. 295. Here the box must be in two halves, and the parting line, shown by a dotted line in the drawing, will be on the two tables in the recesses which are to support the steam-port cores. A box such as this, open at both ends, is formed by gouging out the two half-cylinders lengthways of the grain of the wood, testing them for depth and truth with semicircular templates as the work proceeds; the port-core impressions and the flats at one end are then added afterwards by bradding pieces into each semi-cylindrical half of the box.

Wheel Patterns.—Nothing has hitherto been said regarding wheel patterns, for the reason that they present no complication of form such as do those which require cores. Wheels are nearly always of such a nature that simple moulding only is called for; but when we come to the design of construction, the matter is anything but simple if the pattern is to be of a durable nature. Patterns for locomotive wheels can be made out of flat pieces of wood, turning them in the lathe, piercing with a fretsaw for the spokes, and shaping the spokes by carving and glasspaper. They stand up to the job of moulding, when used at once, but after a time they become useless, because, although the mahogany used is well seasoned, shrinkage takes place, and the pattern becomes elliptical. This nearly always happens, and it makes by far the most lasting job to build patterns up for any wheel

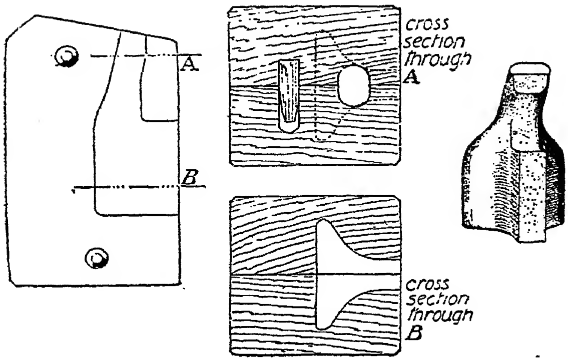


Fig. 297.—*Corebox and core for exhaust port shown in Fig.* 293.

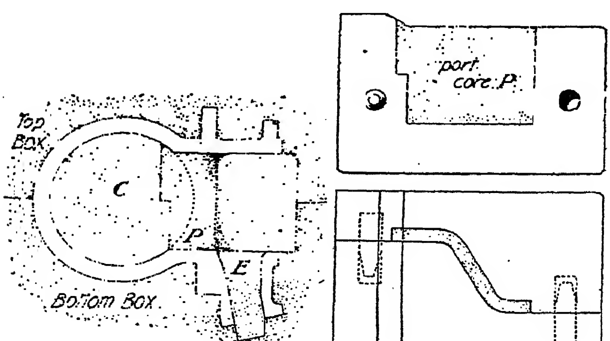


Fig. 298.—*One of the port coreboxes embedded in sand.*

above, say, 3 in. in diameter. By this is meant cutting out each spoke separately, with the grain of the wood running straight along the spoke. At the hub they may all be mitred together to meet at the very centre of the wheel, and have a disk glued over the mitres to form a boss on each side ; or they can all be tenoned into a separately turned boss. At the rim, or tyre, of the wheel, the spokes should be tenoned into the felloes, of which there may be three, four, or six, according to the diameter.

Balance Weight.—Balance weights in patterns for locomotive wheels are best added after the wheel is built up, and for engines with four or six wheels coupled, the weights should be detachable, since the balances for driving wheels are larger than those for coupled wheels, and are often placed at different angles to the cranks. Two balances will therefore be made which can be changed on the same wheel pattern, and either the driving or coupled wheels cast first. This will save the time and trouble of making two separate patterns.

For the making of all patterns and coreboxes there is no finer timber than bone-dry mahogany : Spanish, Cuban, or Honduras ; but it must be thoroughly well seasoned. In very large patterns, yellow pine is employed, but the model maker had better adhere to the finest mahogany, except, perhaps, for such coreboxes as may be thought on the rather big side, when pine can be used. For dowels, ordinary birch dowel sticks can be bought and cut up.

The glue used in pattern making is important. In large patterns, Scotch glue is good, but care must be taken to leave none on the outside of a joint, for the moisture of the sand in the moulding boxes will soften it, and the result will be that some of the sand will come away with the pattern. For small patterns, the best adhesive is a celluloid cement such as " Necol." For this same reason, plastic wood is better than plaster and glue for forming fillets, because the wood dust, of which the plastic material is composed, is mixed with a solution of celluloid or collodion.

Finishing Touches.—Different pattern makers have their own ideas regarding the finishing of their work. Some just give them two or three coats of shellac varnish, made by dissolving the brown flake or shellac in methylated spirit. Such a varnish is transparent, and really, when one has nothing to hide in the construction, no finish could be better. Other craftsmen colour their varnish with different pigments, such as vermilion, orange chrome, red lead, or Indian red ; but all, or nearly all, are agreed in painting prints for cores black, and the coreboxes to correspond. This use of black for prints seems to be quite standard practice in engineering work. Pigment, such as lampblack, is

not used; but a spirit black, an intensely deep purple-grey dye, is dissolved in the shellac solution.

The exterior of all patterns, as well as the insides of coreboxes, should be as nearly glass smooth as possible, and therefore it is as well, in order to attain this end, to rub down lightly with number 0 glasspaper between each coat of varnish, and to pass the varnish after the lac is dissolved, and before using it, through a double thickness of muslin, in order to remove the comparatively large number of insoluble particles of foreign matter.

Contraction of Castings.—A pattern maker usually allows for iron castings from $\frac{1}{10}$ in. to $\frac{1}{8}$ in. per foot and for brass castings double that amount. For aluminium castings $\frac{1}{8}$ in. to $\frac{3}{16}$ in. per foot is allowed.

Shrinkage of Castings

The usual allowance for each foot in length is as follows:

	In.
In large cylinders	$\frac{3}{32}$
In small cylinders	$\frac{1}{16}$
In beams and girders	$\frac{1}{10}$
In thick brass	$\frac{5}{32}$
In thin brass	$\frac{3}{16}$
In cast-iron pipe	$\frac{1}{8}$
In steel	$\frac{1}{4}$
In zinc	$\frac{5}{16}$
In lead	$\frac{5}{16}$
In tin	$\frac{1}{4}$
In copper	$\frac{3}{16}$
In bismuth	$\frac{5}{32}$
In malleable iron	$\frac{1}{8}$
In aluminium	$\frac{1}{5}$

Weights of Wooden Patterns and Metal Castings

1 *lb. Weight of Pattern (without Cores) in:*	*The Weight of the Castings will be, in:*				
	Cast Iron.	*Copper.*	*Yellow Brass.*	*Gun-metal.*	*Aluminium.*
	lb.	*lb.*	*lb.*	*lb.*	*lb.*
White Pine	15·5	18·2	17·5	18·0	5·41
Yellow Pine	14·6	17·2	16·5	17·0	5·11
Beech	10·5	12·4	11·9	12·2	3·68
Baywood	13·2	15·5	14·9	15·2	4·60
Oak	8·5	10·0	9·6	9·8	2·97

CASTING SMALL PARTS

When a number of small parts of somewhat intricate design have to be cast in any non-ferrous alloy, as is often the case in small light mechanical and engineering jobs, it is advisable that the pattern should be as exact as possible in order to facilitate machining, and in order to give a good appearance to the finished part or machine.

The method here described avoids the troubles connected with such small pattern making, and enables awkward shapes to be made easily and quickly ready for the foundry moulders. The plan is to use plasticine—the clay-moulding compound.

The part is fashioned with the plasticine to the size and shape of the finished article, and is allowed to dry thoroughly. This clay " pattern " (to use the founder's term) could be used directly to make the sand mould in the foundry, but it would not withstand continued use. It would be fractious and would also bend and become distorted with the ramming, and probably could only be used for one casting. To overcome this difficulty the plasticine pattern is used to make a plaster of paris mould, from which is easily cast a lead replica of the plasticine pattern, and this lead replica can be used as the pattern to be sent to the foundry and from which any amount of other pieces may be moulded and cast in the metal intended for the job.

The Pattern.—In Fig. 299 we have a supposititious case, in which the pattern is moulded in plasticine. A box (it may be of cardboard) is filled to the level of the top with soft plaster of paris, and the plasticine pattern is laid in it while soft to a depth which will bring the plaster to a level a little higher than half of the depth of the pattern. The plaster is then, when nearly set, carefully scraped away so that its upper surface is level with the top of the box and half the height of the plasticine pattern, as shown in Fig. 300; the plaster is allowed to set hard and the pattern lifted out.

The mould is next taken from the cardboard surround carefully, so that the latter is not injured, and at each side and at each end a slanting half-circular groove is cut down from the top surface as shown in Fig. 301. The top surface (which will be the parting surface) and the four slanting side grooves are varnished with a shellac spirit varnish which dries quickly. The cardboard box is now replaced on the plaster block so that it reaches high up above the surface (Fig. 302). The plasticine pattern is carefully replaced in the mould shape it has made and the whole

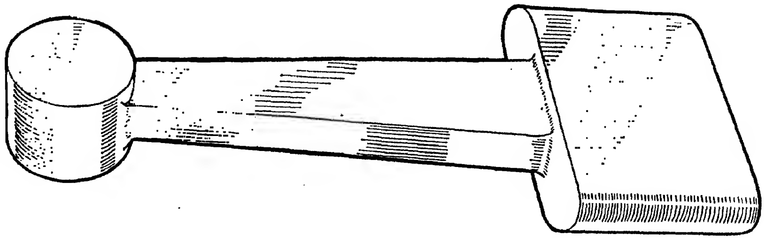


Fig. 299.—The moulded pattern made in plasticine.

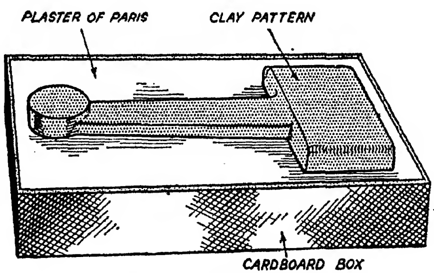


Fig. 300.—The pattern embedded in plaster of paris.

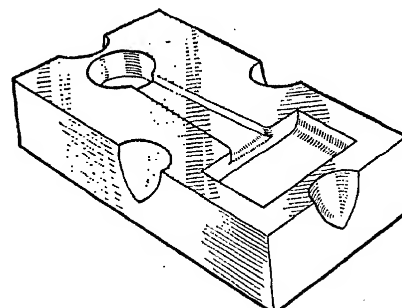


Fig. 301.—Details of the half-circular grooves cut in the mould.

remaining space is filled with fairly liquid plaster and allowed to set.

Two Halves of the Mould.—When hard, the surrounding cardboard box is removed and we have a plaster mould in two halves which will produce the original shape. The slanting grooves at the sides will have formed corresponding projections on the top block of the plaster. All that remains is carefully to drive (from the inside to prevent the drill breaking through into the mould) a runner hole for pouring the lead, and two vent holes to allow the gases to escape and ensure the lead filling the mould.

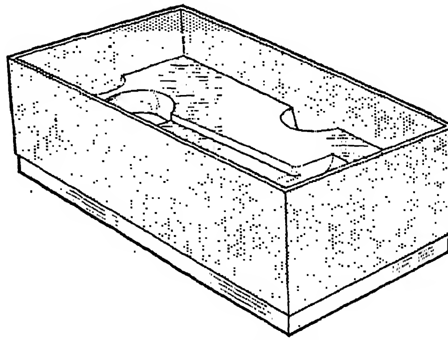
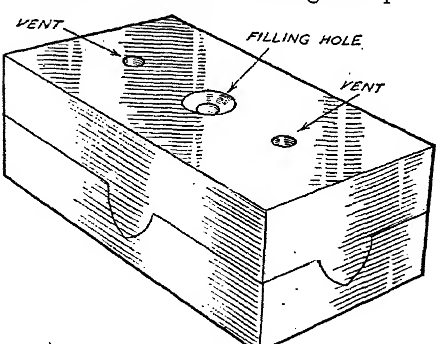


Fig. 302.—The box replaced over the plaster mould.

We now have a plaster of paris double mould (Fig. 303) with side lugs which locate the two halves accurately in position, and can weight down the top half, or clamp it with a clamp, and pour the lead in to form a strong lead pattern, an exact replica of the plasticine model, and can obtain as many as desired and send them to the foundry for casting the part we want, in any metal desired.



.—The double mould.

The lead pattern will stand up to the foundryman's handling, and since we can supply several and easily cast new ones if they get damaged or out of shape, we have a means of getting many castings as we want, while the supplying of several patterns to the foundry facilitates work enormously when a good many of the same pieces are required, for the plaster mould remains intact.

The same procedure can, of course, be followed whatever the first pattern is made of, and since the wood is at times awkward because of its grain making it friable in small intricate pieces it is often an advantage to cut out a rough wooden model with no great accuracy but of ample size. It can be used in the manner shown to get a lead casting. The lead casting should next be trimmed with files, etc., and used as a pattern for the foundry or as a pattern from which to make another plaster mould as described. Thus several patterns can be made at little extra work and expense.

Blowholes.—An expanding alloy to fill holes in castings consists of lead 9 parts, antimony 2 parts, bismuth 1 part. This alloy should be melted and poured into the holes whilst the casting is warm.

Black Lacquer for Castings.—A dead-black lacquer for castings is made from 1 pint of methylated spirit in which is dissolved 2 oz. shellac and 1 oz. ivory black.

Cire Perdu Casting.—This method of casting is convenient for casting single parts and consists of making a pattern in wax, embedding this in plaster, and melting out the wax when the plaster has set. The metal is poured into the mould, and when set the mould is broken away. *Cire perdu* means *hidden wax.*

The method is chiefly employed for matching or " pairing " an existing casting, and for copying an existing object.

Pickling Castings.—Burnt-in sand is removed by pickling iron castings in a solution consisting of 6 parts sulphuric or hydrochloric acid, and 94 parts water. Surface sand can be removed by tumbling or sand-blasting.

Casting on.—In some work items such as studs, long bolts, lugs, etc., which would be too weak if of cast iron, can be placed in correct position in the mould so that they are cast into the casting.

This method will often save fitting work, and simplifies pattern making. Such cast-on parts must, or course, be of higher melting-point than the metal to be cast, and suitable keys should be formed on them so that they cannot work loose. Sometimes it is possible in this way to graft on parts made of dissimilar metal.

SCRAPING FLAT AND BEARING SURFACES

The production of flat surfaces by hand scraping calls for a high degree of skill, and an intimate knowledge of the operation, it follows that the higher the degree of flatness required, the higher the degree of skill required to obtain it.

The majority of work requiring hand scraping to-day is in the production of machine tools for high-class work, and also surface plates for the toolmakers and markers off, and other operators requiring a perfectly flat base from which to work.

Types of Scrapers.—First of all comes the roughing scraper, which is a very robust tool designed principally to remove the bulk of the metal rather than produce a good finish. It may be mentioned that high-class scrapers can be obtained from any good tool shop, and that many engineering firms specialise in producing scrapers of every type as a regular line; also, specially tipped scrapers with cemented carbide tips are becoming more universally used. Wimet-tipped scrapers are sometimes used in engineering shops, but this type of tip needs special equipment, as also does the cemented carbide type, consisting of special green grit Wimet grinding wheels, or else a diamond wheel which is by far the more effective, though much more costly method of sharpening. Other types are shown in Fig. 304.

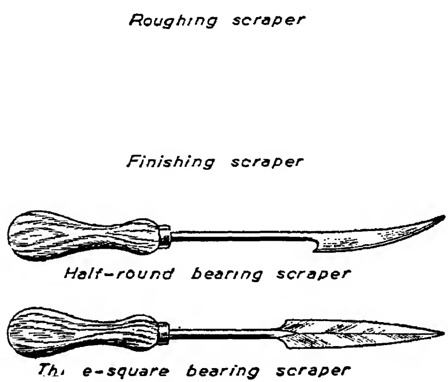


Fig. 304.—*Various types of scrapers*

A diamond lap of the slip type is also a convenient method of sharpening these tipped scrapers. A diamond slip lap usually measures $\frac{3}{8}$-in. square section, and roughly 4 in. long, the diamond dust being bonded on one face about $1\frac{1}{4}$ in. of its length, and

about $\frac{1}{16}$ in. of depth. The cutting compound is paraffin oil, and the method of using the lap is exactly the same as for using an ordinary " India " stone.

Home-made Scrapers.—For most engineering shops the home-made scraper is still the most universally used, and the old file is still the most easily converted into a serviceable scraper. Although all engineers know that this is so, not all know the best method of producing a serviceable scraper of durability, and long cutting life.

The error usually made by those utilising for the purpose old files is to begin by choosing a file which is far too small. The best size is a 14-in. or 16-in. flat file, preferably a smooth cut.

The end may be forged, if desired, in order to make the cutting edge wider, and if this is deemed necessary then the scraper will require rehardening before continuing any further. It should then be placed in a surface grinder equipped with a $\frac{1}{2}$-in. wide 46H grinding wheel to remove all trace of sharpness from the teeth of the file ; being an old file, there should not be much of its sharpness left, though even blunt teeth chafe the hands with constant use. Some mechanics remove all trace of the file teeth with the surface grinding for this particular reason.

All large files of this type have one safe edge, therefore the other must be ground smooth, and all the sharp edges rounded off.

Whether the end has been forged or not the cutting edge must be broken down to about half the original thickness ; hold the scraper in a machine vice at a slight angle, and grind each side equally.

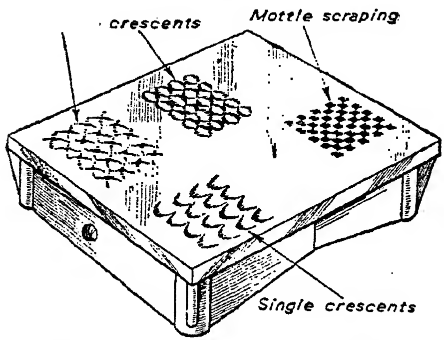
To finish the scraper the edge needs grinding, this may be done on an ordinary tool-grinding machine moving the scraper at a slight arc, to give a slightly rounded edge which helps the scraper to remove heavy cuts with a minimum of effort.

A finish scraper is exactly the same as the rough one in respect to the choice of files—a large smooth one—and the end need not be forged to obtain extra width, the file width being ample. Beginning about $\frac{1}{4}$ in. from the cutting edge, and continuing for $1\frac{1}{2}$ in., the thickness of the file will be reduced by forging to $\frac{1}{16}$ in. Reharden and surface grind as for the previous scraper, again reducing the $\frac{1}{4}$-in. tip to about half the original thickness ; round off the sides as before. The cutting edge of the finishing scraper should be straight, and may be either square or else cut with two small angles, each giving to the centre line of the cutting edge an angle of 10° or 12°, which will be found very effective.

The forging will give a slight spring and combined with the

negative rake on the cutting edge will result in much smoother cutting and consequently better finish.

Work suitable for Scraping.—Although all work made of cast iron is suitable for scraping, great care must be taken, especially in the manufacture of surface plates—easily the most common object of toolroom equipment to be scraped—that the work is worth while scraping. Cast iron has tendencies for frequent movements in formation, it is therefore almost impossible to keep a flat surface once obtained because of this movement, unless a few common-sense rules are followed.



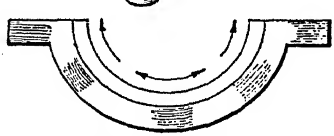


Fig. 305 (*above*).—*Surface plate showing various methods of scraping.*
Fig. 306 (*below*).—*Half-bearing, showing direction of scraping.*

First, the thickness of the actual surface plate should be considerable, $\frac{7}{8}$ in. after machining being regarded as about right. Care must be taken to ensure that this thickness is maintained throughout the entire area of the plate. It is noticeable that where great variations exist in the thickness of the plate the true plane is lost so much sooner owing to movement in the thin part, the most frequent spot for this variation being in the centre of the plate, or else on one corner owing to poor casting.

If the surface plate to be trued suffers with either of these faults to any great degree, say $\frac{3}{16}$-in. variation, then the plate is not worth the time taken to hand scrape, but should be planed or shaped to a good finish and used.

In addition to having a uniform thickness of about $\frac{7}{8}$ in., a good surface plate needs to be substantially braced with webbing; about the most common type is shown in the sketch, and the usual dimensions for the bracing are 2 in. high and $\frac{5}{16}$ in. thick.

The procedure adopted in the production of a new surface plate is first of all to machine all over the top and the four sides,

removing about $\frac{3}{32}$ in. of metal all round ; a good finish should be put on, and the use of a good spring tool for finishing will ensure the finish being good.

Remove the plate to the bench and after carefully filing off all the sharp corners, proceed with the scraping. There are two standards of scraping, one which is merely a breaking up of the surface with the scraper, which practice if often followed in the commercial production of surface plates, and if skilfully done gives a good and fairly long lasting working face. The second method is a thorough scraping all over by hand, removing all the machined surface. This second method is much slower and much more expensive, but the compensation comes in the higher degree of flatness, and a definitely longer life under trying conditions.

Breaking up the Surface.—Breaking up the surface means that a high finish is put on the surface plate while being machined and then a series of small crescents are hand scraped on with the roughing scraper. These crescents could be contained in half an inch and are cut at about 45° to the sides, first in one direction until the whole surface is covered and then in the opposite direction, the crescents joining each other at the beginning and end of each crescent. This method is very speedy, and the appearance is quite good, the crescents breaking up the machine surface, thus enabling such tools as scribing blocks and height gauges—which have a very highly finished base—to move freely over the surface plate without sticking or jerking.

The size and shape, and the direction, become automatic after a little practice, but until one becomes proficient it is a good plan to mark off the surface plate using a soft lead pencil. Keeping the long side of the plate square, space off lines $\frac{1}{2}$ in. apart and parallel to the side, turn the plate at right angles, and repeat the marking off.

Turn the plate diagonally so that the marked-out squares are presented point first, take the roughing scraper, handle in the right hand and the left hand half-way down the blade, present the scraper at about 30° to 35° to the surface plate, and with an oscillating movement to the left scrape from the bottom point to the top point of each square. This oscillating movement may be described as a rather quick movement of the wrist while moving the scraper forward from point to point ; the wrist movement has the effect of rolling the scraper edge while travelling forward, beginning with the inside point of the cutting edge and finishing with the outside edge, so forming a crescent beginning quite narrow, broadening out in the centre and ending again quite narrow (see Fig. 305).

When the whole of the surface area has been covered in this manner turn the plate completely round and repeat the whole process, the scraper will move in exactly the same manner and direction as before, and will form two crescents going in opposite directions and joining at the extreme ends. Finally, rub the surface just scraped with a block of hardened steel which has at least one surface-ground face. The ground face would be laid on the plate, moving in straight lines as though ironing; apply a reasonable pressure and cover the whole of the surface area. This procedure has a twofold purpose: first, it removes the host of tiny ridges left by the scraper; secondly, it tends to press the cast iron dust back into the pores of the plate giving a closer grain and consequently a longer lasting surface.

Complete Surface Scraping.—The machine treatment of the plate needs to be as carefully finished as before, and when laid on the bench the whole of the surface area is covered by the roughing scraper to remove all trace of the machine marks. The scraper this times moves in straight lines of about $\frac{1}{4}$ in. in length and the area covered with each series of strokes, about three in number, is about $\frac{1}{4}$ in. With practice the tiny pause between each series of strokes is so small as to seem continuous, and the surface plate is covered in a surprisingly short time.

After having removed all traces of the machining, the next important step is to make the surface absolutely flat, the usual and by far the easiest way to do this is to use a master surface plate for checking in the following manner.

Carefully clean the master plate and then smear over the surface a medium thin coating of blue. (The blue commonly used is ordinary prussian blue oil paint.) Special engineers' blue is obtainable though not so widely used. Red lead thinned down with lard oil is often used as a marking compound, and is quite satisfactory for the job.

Remove from the work all traces of the scraping dust with a clean cloth, place the work face downwards on the master plate, and move once or twice across the surface with a circular movement. Do not rub the two surfaces together more than once or twice because the result will be only excessive wear on the master plate; this is to be avoided at all costs.

Expose the work on the bench and it will be seen that the surface is covered with numerous blotches of the marking.

Because the work was carefully machined before scraping the marking should be found to be quite close and without any great variations in flatness, therefore the finishing scraper may be brought into use.

Carefully scrape away the marking, using the same short stroke as before, wipe clean, without using more compound, wipe the master lightly thereby producing a thinner coating of colour; repeat the rubbing process and re-scrape.

Repeat the whole process until the colour on the master is the faintest smear, and the reproduction in high spots on the work are so close together as to be continuous. It is unnecessary to mention that the higher the number of high spots per square inch, the more accurate the flat surface and the longer the life of the plate.

No particular design of scraping is used when a very highly finished surface plate is produced, as the short strokes of the scraper, in straight lines, and the very closely spaced high spots combine to give a very fine mottled appearance which looks good viewed from any angle.

Scraping without a Master.—It is interesting to note that flat surfaces may be produced to a very high degree without the aid of a master plate, though an intimate knowledge of the process is necessary in order to produce the desired flatness.

Three plates of the same approximate dimensions are required and all must be planed up to a good class finish. They must also be scraped all over obliterating completely all the machine marks; the roughing scraper using the short stroke described previously is desirable (see Figs. 307 and 308).

First of all the three plates should be numbered, then No. 1 and No. 2 should be scraped to each other. It will be understood that both plates must be scraped and as far as possible an equal amount should be removed from each plate. When these first two plates show a reasonable degree of trueness, it is not necessary to continue scraping to achieve an exceptionally high degree of accuracy at this stage. No. 1 plate and No. 3 plate should be scraped together, and again it must be borne in mind that this time only No. 3 plate will be scraped.

Now No. 2 and No. 3 plates will be scraped, this time an equal amount of metal will be removed from each plate.

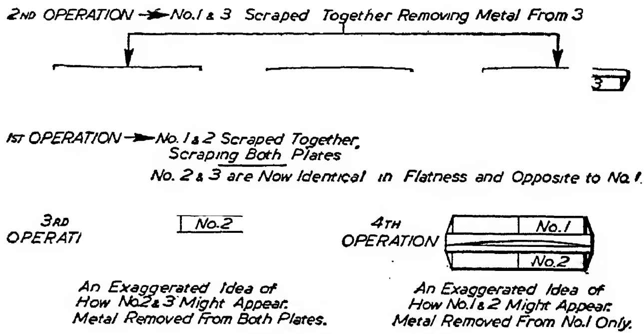
No. 1 and No. 2 are scraped together next, the metal being removed from No. 1, and then No. 1 and No. 3, removing the metal from both. This sequence of scraping must be carried through until all three plates are interchangeable thus proving themselves true planes. The sketch will show the reason and sequence perhaps more clearly.

Special Fixtures.—When machine tools need renovating it is often necessary to make special fixtures, for example the scraping of Vee-slides on a surface grinding machine cross-slide.

It is of course imperative that these slides must be both exactly the same height, and perfectly square with each other, therefore assistance must be obtained from a fixture designed for this particular job.

The fixture needed is composed of two blocks of mild steel long enough to cover the machine Vee, and of heavy section. The true inverted-Vee is machined on, and the two blocks are strapped together by bolting two pieces of heavy channel iron across.

When all the holes have been drilled in the Vee-blocks they are hardened and ground, then the base and top edges of the channel



Figs. 307 *and* 308.—*This sequence must be carried through until the plates are interchangeable.*

iron are ground, and the parts fastened together, checked to inspection limits, and used in the manner of a master.

The inverted-Vees would, of course, be scraped up first to the master, and then the Vees on the cross slide would be scraped to correspond exactly to the prepared bed.

Numerous other fixtures may be made in the same manner at quite a small cost and are absolutely necessary on many jobs demanding extreme accuracy.

Scraping Bearings.—The scraping of bearings does not differ much from flat scraping in the fundamental principle, that is the production by hand of a true surface.

The material used in the bearings may be brass, bronze, gun-metal, white metal, babbit metal, antifriction metal, and various others.

Bearings are in two principal classes, the solid or bush type, and the half bearing.

The half bearing requires perhaps the greater skill in scraping up true, and even when both new bearings and shaftings are used the scraper plays an important part in ensuring the long life and trouble free running of the work.

When the work to be done is the refitting and scraping of old bearings and shaft, the procedure usually adopted is this. First the shaft bearings are trued up in either a lathe or universal grinding machine; only sufficient metal will be removed to make the bearing perfectly round again. The half bearings are cleaned down, and if they are being renovated for the first time there will probably be a small exposure of brass, part of which may be removed to bring the largest or worn part of the bearing down to the shaft diameter, there may also be some thin shims which may be removed altogether or else made thinner. If neither of these two conditions exist then sufficient material must be removed from the top half of the bearing to enable the largest diameter of the bearing to be about ·003 in. smaller than the shaft.

On the edges of the bearing where the two halves meet, file a $\frac{1}{32}$-in. chamfer. With the top half of the bearing removed commence the scraping of the bottom half.

In the event of the job being a press camshaft and bearings there would be two bearings on the shaft and two half bearings and, of course, the two bottom halves of the bearings would be scraped in at the same time.

Blue the two bearings on the camshaft using ordinary prussian blue on a piece of clean cloth, place the shaft in the two half bearings and rotate once or twice; it will be found that the blue shows up the high spots leaving the worn or low part untouched; therefore, with the aid of a scraper, the colour is removed and eventually a true face will be obtained.

The two top halves of the bearings are scraped separately, the bearings being held in a vice while being scraped. Here again the shaft is blued and the high spots are scraped away until a true surface is obtained. The whole job is now assembled and any slight adjustments made, perhaps the addition of a shim, or an extra little skim off the bearing face until the bearings are satisfactory, the work must be run in very carefully and not allowed to overheat because of the risk of seizing and the consequent scoring and spoiling of the bearing surfaces (see Fig. 306).

Scrapers for Bearings.—Bearing scrapers differ from flat surface scrapers in the respect that the bearing scraper cuts on the side while the flat surface scraper cuts on the end.

There are two types of bearing scraper in common use: one is the three-square scraper, this one being more often used while scraping bushes; the other is a half-round one, this scraper is set and hollowed.

The sketch shows exactly the shape and section form for this type of scraper which has been designed for this particular job. Many commercial scrapers are on the market to-day which are ideal for the job and have good cutting qualities and a long life.

Again, as in the case of the flat scraper, a good and reliable scraper may be produced from an 8-in. smooth cut half-round file. The bearing scraper must be forged because of its shape.

The blade or effective part of the scraper is about $2\frac{1}{2}$ in. long, and is forged into part of a 10-in. circle, the width of the blade is the width of the file at the extreme end of the blade and narrowed down to approximately $\frac{1}{4}$ in. at the tip.

The remaining length of the file is forged down to about $\frac{3}{8}$ in. in width right to the tang, the bottom face of the scraper which is flat, measuring across the scraper, should have a groove in it in order to leave two cutting edges about $\frac{3}{32}$ in. wide on the blade; this groove may be either forged or ground in before the blade is formed into part of a circle.

On the two edges of the blade grind a $12\frac{1}{2}°$ cutting angle. Harden and temper and finally grind up the blade and hone to a fine cutting edge.

A three-square scraper is in shape exactly like a three-square file, the file teeth being removed by grinding, and the cutting edges honed.

When using the half-round scraper the practice when scraping a half bearing is to remove from the bottom of the bearing with an even circular movement, and when scraping the sides work from the inside to the edge of the bearing, these points are explained in the sketches.

The three-square scraper is usually used on a lathe when scraping bushes, and is held slightly behind the centre line; movement is in straight lines only, the movement of the lathe against the scraper removing the metal.

Whilst good and serviceable scrapers can be produced from converted files as already mentioned; there are several substantial reasons against such practice.

Firstly, many steel manufacturers now produce a special high-speed steel particularly adaptable for producing scrapers. It will be found that the conversion of old files into scrapers incurs greater expense than obtaining such steel.

Secondly, as all scraping tools require a certain degree of flexibility and "springiness" it will be found that merely to remove the worn teeth of a file leaves a shank much too thick and rigid for successful scraping. Steel shanks specially manufactured for scraper tools are seldom thicker than $\frac{1}{4}$ in. and suitably forged or thinned at the cutting end, whereas the 14-in. or 16-in. file will finish up at $\frac{3}{8}$ in. or more after the teeth have been removed.

Thirdly, when a file is softened and forged the user very rarely succeeds in obtaining the same degree of hardness afterwards, and thus trouble is often caused in the shape of a constant need for re-sharpening of the scraper.

Sharpening.—It is known that one of the chief hindrances to successful hand scraping lies in the kind of sharpening afforded the tool. Most engineering shops provide but the barest provision for grinding or stoning such tools, this process being usually

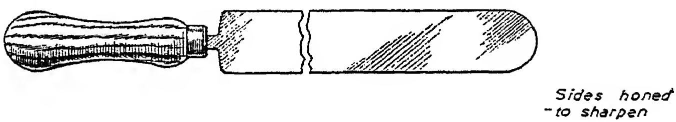


Fig. 309.—A round-end bearing scraper.

carried out by rubbing the end of the scraper on a flat oilstone or piece of carborundum. Only a very skilful workman can produce a correct and durable cutting edge in such a way.

It should be realised that the action of the scraper is essentially a cutting one similar to that of the planing or shaping tool, success and length of life depending upon the maintenance of correct cutting rake after each re-grind. A disc-shaped oilstone should be employed, this being rotated by power and set up in such a manner that both the rim and side faces may be employed for stoning purposes. A rigid fixed rest should be installed and attached to the top of this rest should be a block of cast iron or even hardwood upon which the scraper can be rested, the block tilting the tool to the requisite angle, which incidentally should not exceed 10°.

Thus, in this simple way the tool is presented at the same angle to stone every time and correct cutting rake angles are maintained. It is a good plan to stone the end of tool on the periphery of the stone, and the sides of the tool on the flat sides of the stone. An oilstone about 8 or 9 in. diameter and about $\frac{3}{4}$ in. thick will be

found very suitable. A speed of approximately 80 to 100 r.p.m. will produce best results and ensure longest life to the stone.

Round End Bearing Scraper.—Fig. 309 shows what is known as the round-end bearing scraper. The cutting end of this type

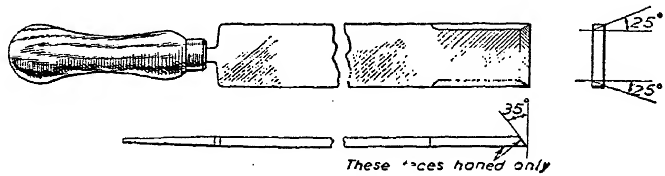
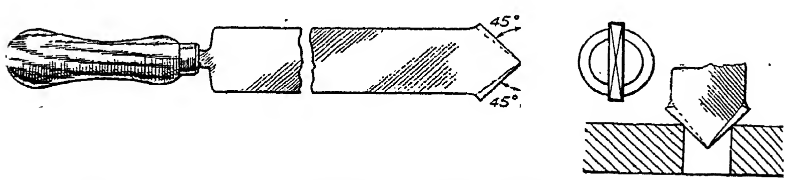


Fig. 310.—A useful form of scraper.

of tool is rounded semicircular in shape, this end being honed up to provide two cutting edges. Very little front rake should be provided, in fact if the edge is ground perfectly square two good cutting edges will result. The flat sides are stoned up perfectly flat. This tool will be found exceedingly useful when lengthy bearings have to be scraped. Using a half-round bearing scraper of conventional design difficulty is often experienced in that the user's hands prevent tool being used throughout full length of bearing.

The round-end scraper may be used for either lengthwise strokes of cut, or circumferential ones as in the case of the half-round type tool. In the hands of a skilful workman very good work can rapidly be produced. The tool shape is suitable for either a rougher or finisher type of scraper.



Figs 311 and 312.—A scraper for removing corners of drilled holes.

Two Useful Scrapers.—Fig. 310 illustrates a form of scraper which has been found from extensive experience to be extremely useful. Its special feature consists in a backing away at a convenient angle of a short portion of each side edge as shown. This permits the cutting point of tool to be used very

close into corners or against ledges, etc., often met with in machine-tool components.

The tool here shown is specially ground at cutting edge so as to be applicable for use on steel. Only one cutting edge is provided, and a substantial rake supplied as indicated. The tool shank should be about 12 in. long, not more than $\frac{1}{8}$ in. thick, and about $1\frac{1}{4}$ to $1\frac{1}{2}$ in. wide.

The third type of scraper, as shown in Figs. 311 and 312, is not intended for flat or curved surfaces, but for removing corners of drilled holes, and the forming of countersunk recesses for housing Vee-head shaped screws, etc. It will be noted the tool is provided with a Vee-shaped cutting end, consisting of two hones, sides located at 90° apart, suitably backed off to enable clockwise rotation of tool or right-hand cutting.

BLACK AND BLUE FINISH

Gun-metal finish is also known as carbonia finish, and the type of finish desired is governed mainly by the finish of the part before the special treatment is given. Cold drawn or highly-polished parts will take a glossy black finish: those made from normal stampings will have a rather duller finish, while any part sand-blasted before treatment will have a black matt finish. To apply this finish, the job is positioned loosely in a retort with a small quantity of charred bone and heated to 370–425° C.

When the parts are completely oxidised, the temperature is permitted to fall to approximately 345° C. when a mixture of bone and 1 or 2 tablespoonfuls of carbonia oil are added. Heating is then continued for some hours. When the work comes from the retort, it is a dull grey black, and by immersing in sperm oil or tumbling in oily cork, a uniform black finish is obtained.

The blueing of polished articles is achieved by introducing them into a bed of hot charcoal about 2 ft. in depth. When the desired shade of blue is developed, the parts are rubbed vigorously with waste that has been dipped in raw sperm oil. A good blue can also be produced on iron by first depositing a thin coating of electrolytic copper, using either the sulphate or cyanide bath. The copper-coated steel is then made the cathode in a solution 1·25 oz. per gal. cupric acetate and 0·50 oz. per gal. of gelatine. Through this solution is passed a current of 1·5–4·0 amps per sq. ft. using copper as the anode. After copper deposition for about 15–20 min. the cathode is washed in water and immersed for five min. in a 5 per cent. cupric acetate solution. Hues of startling intensity are produced, one after another in succession, until in the end a deep blue is obtained.

GAUGES AND GAUGING

Modern production methods, which usually call for rapid repetition work, demand an equal measure of speed and accuracy in checking finished and partly finished components. Since it is necessary to accommodate any slight inaccuracies which may occur in machining or grinding, it is usual for the gauges used to be of the " limit," or " go " and " not go " type.

Plug and ring gauges are widely used in most workshops and factories. If it is desired to turn a bush 3 in. in diameter, with a tolerance of ·002 in., and a specified high limit of plus ·00125 in., and low limit of minus ·0075 in., an ordinary plug gauge exactly 3 in. in diameter will, of course, be of little value; although it would not enter the bush if this were undersize, it would enter any hole exceeding 3 in. in diameter (Fig. 316).

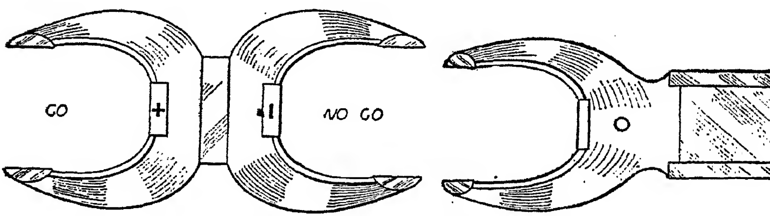


Fig. 313.—Two types of snap gauge.

By using a limit plug gauge, however, the hole can be machined accurately so that the " go " end of the gauge, ·00075 in. undersize, will enter, but the " not go " end, which is 3·00125 in. in diameter, will not pass through. Thus, although a tolerance of only ·002 in. is permitted, the work can be carried out with considerable accuracy even by an unskilled mechanic.

A similar procedure is adopted in the case of external limit ring gauges, used for checking the diameter of a circular bar or tube. A different type of external limit gauge, suitable for use on either round or flat work, is shown in Fig. 314. The distance between the two pairs of gauge faces is arranged to conform to the high and low limits.

Snap Gauges.—The " horseshoe " gauge or " G " gauge, as it is sometimes termed, is often used for measuring length of material, the jaws being hardened and ground, and then dressed with an oilstone until the exact length required is obtained. By extending each jaw on the opposite side of the gauge a pair

of "go" and "not go" limit gauges can be obtained (Figs. 313 and 314).

A type of snap gauge which is sometimes used to facilitate rapid checking of the diameter or thickness of parts takes the form of a rigid frame, one arm of which carries two accurately machined gauge faces, opposite which are adjustable gauge faces, accurately set by a master gauge to the high and low limits. The work can be kept within the necessary tolerances by sliding the snap gauge over it, the outer pair of contacts passing over the work, and the inner pair failing to do so when the dimension is correct.

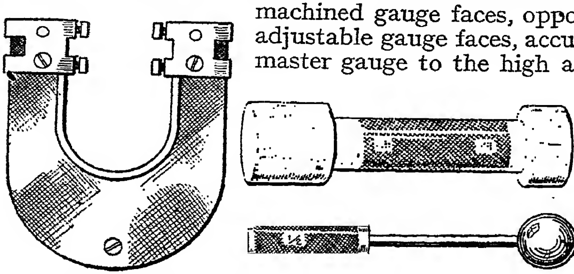


Fig. 314.—Adjustable snap gauge, "go" "not go" plug gauge, and ball-ended gauge.

Pneumatic Micrometer.—In order to overcome the problem of wear on the faces of plug, ring, or snap gauges, the Solex pneumatic micrometer has recently been widely adopted in modern factories. The principle of the pneumatic micrometer can be appreciated from the accompanying sketch. There is no contact between the measuring faces of the micrometer and the components, the dimension being recorded by the relative difficulty which compressed air experiences in escaping from jets separated by a fraction of a thousandth of an inch from the surface of the article to be measured (Fig. 317).

The compressed air is admitted to a constant-pressure chamber at the head of a tube which is connected at the base to a water-filled cylinder. A second tube dips into the cylinder and provides an outlet for surplus air, thus maintaining the constant pressure in the upper chamber. A third tube is

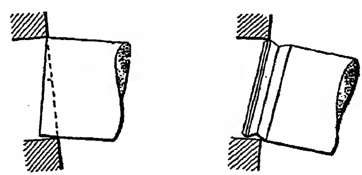


Fig. 315 (left).—If the ordinary type of plug gauge is not square with the hole it jams as shown here. This results in the formation of a pressure ring.

Fig. 316 (right).—Due to the provision of a groove near the end of the "Pilot" gauge jamming and wear are prevented.

connected either to a plug gauge which has jets drilled at intervals around its walls, or to the inner faces of the blocks of a snap gauge.

It will be seen that when the article to be measured is placed in the snap gauge, or when the plug is passed into a cylindrical bore, the ease with which the air can escape depends on the clearance between the adjacent surfaces; the restriction of the air flow from the jets is transmitted to the calibrated glass measuring tube, forcing the column of liquid down in the tube.

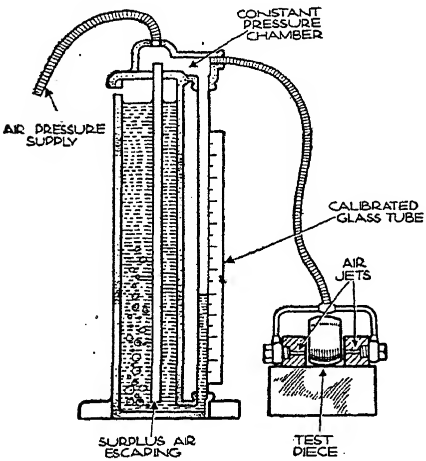


Fig. 317.—A diagrammatic sketch of the Solex pneumatic micrometer, adapted in this case as a snap gauge.

So sensitive is this micrometer that variations in measurement are magnified 9,000 times, enabling measurements to be made within $\frac{1}{10000}$ in. without the necessity for any appreciable degree of skill on the part of the operator.

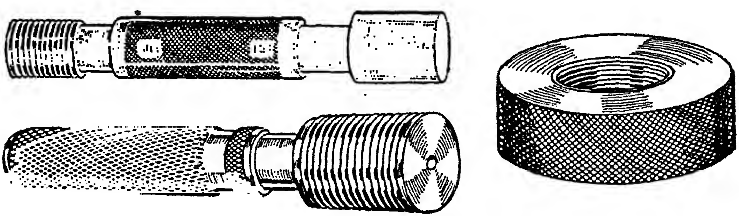
These gauges can be used to replace dial indicators, since they can be arranged, if necessary, to give a magnification as high as 20,000 to 1. The micrometer can be used in tension with hooked gauging elements for measuring the internal diameter of ball-race tracks and similar parts, or can be permanently attached to machine tools. For tool-room work a specially sensitive instrument enables readings as fine as ·000002 in. to be taken, enabling standard gauge blocks to be checked.

For special applications a modification of the system, using mechanical contact air-pressure gauges, has been developed in which the gauge element or anvil operates a valve, thus regulating the flow of escaping air. Readings may be taken in this way to ·00005 in. Employing the system for snap gauges, a tolerance of plus ·00005 in. and minus ·000025 in. can be held quite easily.

Dial Gauges.—There are a number of different methods of employing a dial gauge for comparative purposes. Most readers will, of course, be familiar with this type of gauge, in which a

plunger operates a pointer moving around a dial graduated in thousandths of an inch. The gauge is provided with a clamp, allowing it to be attached to the arm of a scribing block or similar carrier, so that the plunger of the gauge can be brought into contact with the component to be tested. In the case of a rotating part any eccentricity or lack of truth will immediately be revealed by fluctuation of the pointer.

More than one gauge can be employed at a time, enabling simultaneous checks to be made. At one car-manufacturing works, for instance, fifteen dial gauges are arranged to touch every vital part of an experimental back-axle assembly while the drive is being transmitted at maximum torque. The dial



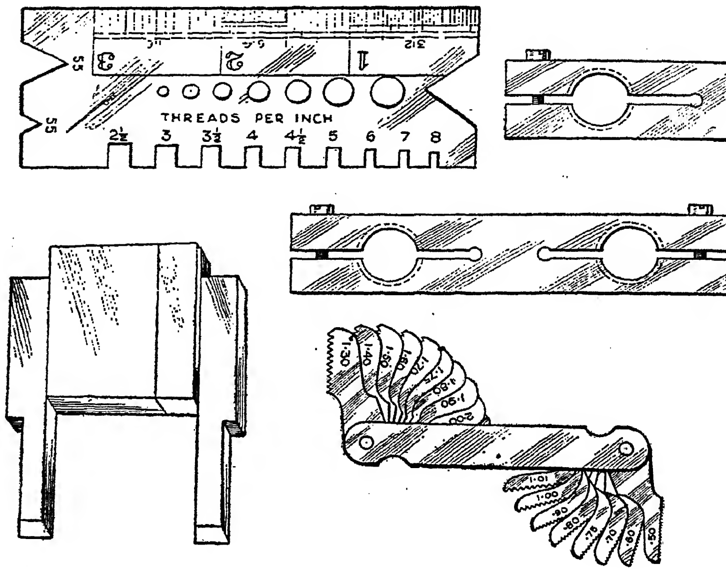
Figs. 318 *to* 320.—*Various screw gauges.*

indicators reveal the side-thrust on the bevel pinion, the lift on the end of the pinion and on the crown wheel, the side-thrust of the crown wheel, and the end-float on the pinion. Side and endwise movement of the differential-bearing caps, movement of the differential cage, and any movement of the crown wheel on the opposite side can also be detected. Twist of the banjo axle-casing or deflection at the end of the casing, and also movement at the wheel hub, will be shown up.

A small dial gauge is frequently employed to check the circularity of bores or chamfered seatings which must be concentric with a pilot bush or guide, a typical instance being the valve-seatings of an internal-combustion engine. In this case a pilot rod of the correct diameter is inserted in the valve-guide or the pilot bush, and the dial gauge is fitted to the pilot, with the contact arm adjusted against the valve-seating or the interior surface of the bush, as the case may be. On setting the needle to zero and rotating the indicator slowly, movement of the needle will reveal inaccurate machining or grinding (Fig. 323).

Measuring Internal Diameters.—The cylinder gauge is a form of gauge which enables internal diameters to be accurately

measured, both for circularity and parallelism of the bore. Modern instruments of this class are generally provided with self-centring slides enabling readings to be taken with the minimum of trouble. The dial gauge is in this case fitted with an adjustment enabling slight initial outward pressure of the



Figs. 321 *and* 322.—*Johannson slip gauge, screw pitch gauge, adjustable screw pitch gauge, and square- and V-thread gauges.*

plunger to be exerted against the cylinder wall before the needle is set to zero.

It is then a simple matter to rotate the gauge around the bore, movement of the needle revealing any ovality, and to slide it up and down to detect a tapering bore. With some types of cylinder gauge a cross-check can be applied by locking the contacts while the gauge is in the bore, and then measuring the actual diameter across the slide and the plunger of the gauge with a micrometer calliper.

The cylinder gauge can, of course, be employed during the final stages of machining or grinding a bore to size. A micro-

meter calliper should be adjusted to the exact size to which it is intended to grind the finished bore. The cylinder gauge should be fitted between the contacts of the micrometer and the dial of the gauge rotated to indicate zero. By passing the cylinder gauge into the bore at intervals during grinding, the exact amount of metal which it is necessary to remove will be indicated by the position of the needle on the minus side of the zero mark.

A different method of measuring internal diameters is with a micrometer caliper used in conjunction with a telescoping gauge. A telescoping gauge is first centred on the cylinder bush, or similar component, and the contacts are locked by tightening the handle. The gauge is then placed between the contacts of the micrometer calliper.

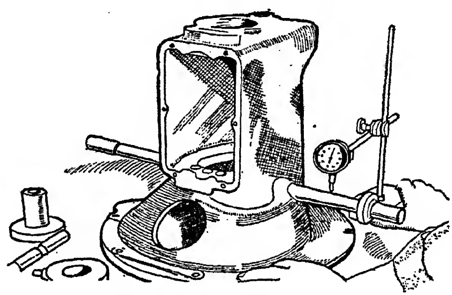


Fig. 323.—A dial gauge being used to check automobile gearbox castings with the aid of a bar gauge.

Limitations of Ordinary Calipers.—Apart from checking tolerances during production, a variety of actual measuring instruments are required in the average factory or workshop. Ordinary calipers, although convenient for measurement and comparative purposes, are seldom used in production work, since the spring of the legs is bound to be a source of error, while the necessity for tapping the conventional type in order to adjust them is sufficient to condemn them for modern precision work. Vernier caliper gauges are, of course, invaluable when accurate measurements must be taken. In most cases, however, a micrometer caliper gauge or an inside micrometer gauge with a selection of distance-pieces is more generally used. In view of the wide use of the micrometer, which is to be found in various forms in nearly every workshop, a detailed description of its principle and use is hardly necessary.

Master Gauges.—It is, of course, imperative that the various gauges and measuring instruments just described should be capable of being checked from time to time, since with conventional gauges contact with the work is bound to cause wear and to impair their accuracy. The standard of accuracy in most large factories is the Johannson gauge block system (Fig. 321).

SELF-TIGHTENING SCREWS

It is often necessary to provide a self-tightening screwed fitting which does not require a spring washer or other holding device. The accompanying illustrations show some of the simple ways in which this may be accomplished.

Fig. 324 shows a screw with countersunk head. It differs

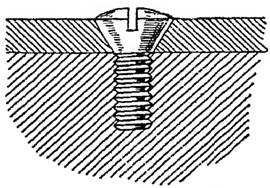


Fig. 324.—A screw with a steep angle of countersink on the head.

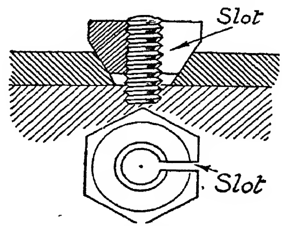


Fig. 324A.—How two pieces may be joined with the least projecting height.

from an ordinary screw in that the angle of the countersunk part under the head is very much more acute than the standard.

The hole is tapped and the top of the hole is opened to a

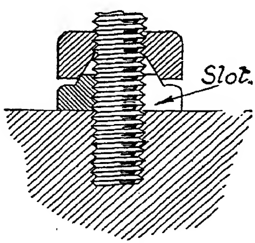


Fig. 325.—A conical type of locking nut.

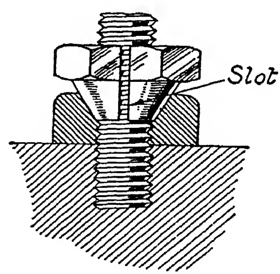


Fig. 325A.—Another conical type of lock nut.

steep angle and the screw head has an angle to correspond. When screwed down tight it wedges by reason of the acuteness of the angle and will hold without spring washers against any ordinary vibration. It has the advantage that it can, if necessary, have a flush head, thus allowing it to be used where a projecting

head would form an obstruction to some other part of the mechanism being assembled. Given a cutter of the angle shown, 60°, and the head turned down to this angle, it makes a simple and very secure fastening.

In Fig. 324A is shown how two pieces (as in Fig. 324) may be joined with the least projecting height by a stud and nut, thereby avoiding the use of a spring washer or lock nut. The hole in the upper piece is tapered to 60° and the bottom of the nut is similarly tapered to the same angle. A slot is cut in the nut, as shown in the plan view below. When screwed down tight the taper on the nut, combined with the taper in the hole, causes the nut to close on the threads of the stud and hold very tightly both on the taper in the piece and on the threads of the

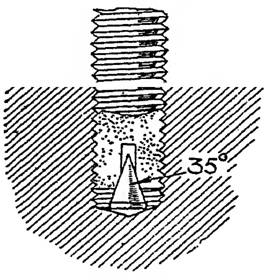


Fig. 326.—*A simple method of fastening a stud in its hole.*

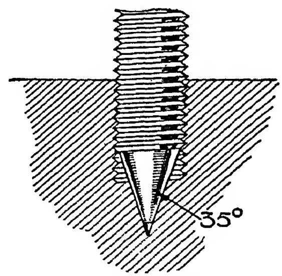


Fig. 326A.—*A pointed stud will also hold tightly.*

stud. It has the advantage of giving the full length of thread in engagement with the stud combined with little projection beyond the surface of the work. If the nut is slotted on the top, for a slotted screwdriver, it can be made flush.

Conical Lock Nuts.—Two forms of lock nut which will hold better than the usual method of using two ordinary nuts are shown in Figs. 325 and 325A. They both act on the same principle. In the first (Fig. 325) the lower nut has its top turned away to a cone shape. The upper nut is recessed on its under side to a corresponding angle. When one is screwed down on the other these tapers engage and hold tightly. The bottom nut may be slotted as shown and the top nut locking down on it contracts it on to the stud threads.

In Fig. 325A, the bottom nut has a conical recess in its upper side and the top nut a corresponding male cone on its under side to the same angle. The top nut is slotted and contracts

inside the cone in the bottom nut, and so grips the threads on the stud very tightly.

Often where studs are used, there is a difficulty because, when unscrewing a nut and lock nut upon them, these two nuts hold tight to the stud and the stud is drawn out with the nuts instead of the nuts unscrewing off the stud.

Expanding the End.—In Fig. 326 is shown a method of fixing the stud so tightly that nuts and lock nuts upon it can be removed without any chance of the stud being withdrawn. The end of the stud is drilled for a little distance and opened to an internal taper by a cutter. Then the end is slotted by a saw cut for a little distance from the bottom, and a tapered steel

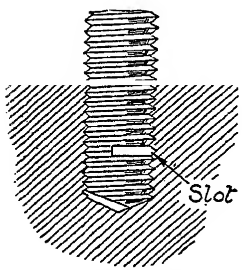


Fig. 327.—A method of binding the stud in the hole.

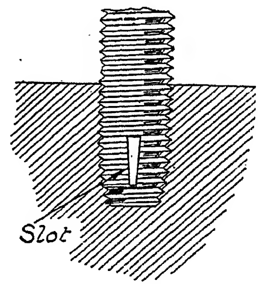


Fig. 327A.—A slotted stud used in a taper hole.

cone is laid in the bottom of the hole. When the stud is screwed down, in assembling the part, the cone expands the end of the stud in the threads in the hole and an extremely tight fitting results. The stud will only be capable of being withdrawn by a pressure greater than that which would unscrew the nut and lock nut.

Another method of securing a stud against turning is shown in Fig. 326A. Here the bottom of the stud hole is tapered by a taper-ended drill used after the hole has been tapped. The end of the stud is cleared of thread for a little way and tapered to the same steep taper as in the bottom end of the hole. The angle is acute—35°—and when the stud is screwed down it jams tight in the taper in the hole.

Binding the Stud.—Other methods of securing studs against easy withdrawal are shown in Figs. 327 and 327A.

DIE CASTING

Improved technique, and the fact that alloys have a low melting-point and remarkable physical properties coupled with stability, are leading to the increased use of die-castings. In many instances they are even being used to supplant parts fabricated from pressings with great success, as not only is assembly time reduced or completely cut out, but a much cleaner and neater product possessing great strength is the result. It is hard to find a branch, at all events in the lighter types of engineering, in which die-castings are not or could not be employed with success. This is borne out by the fact that, to quote even a few instances, such castings are now used in large numbers in the automobile, motor-cycle, electrical, small mechanical, gramophone and wireless, clock, instrument making, typewriter and calculating machine, and toy industries.

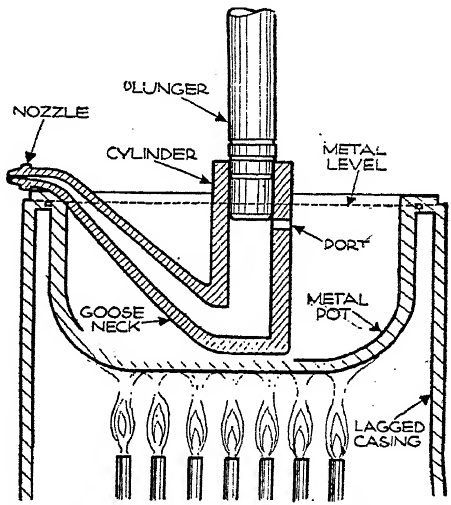


Fig. 328.—*The metal pot of a die-casting machine.*

Although die-castings have only come into use to any great extent generally within recent times, the origin of the process dates back a considerable number of years. As a matter of fact it is close on one hundred years since printer's type was first cast by machine on practically the same lines that are in use for general die-casting at the present moment. Doubtless, at that time, the need for such a revision of methods was partly brought about by the natural desire for increased production, but in all probability the change was necessitated by the difficulty or impossibility of making sound and clear-cut small type by ordinary gravity-casting methods.

Sand-castings.—Die-casting is essentially a process suited to the production of certain types of castings in quantities. In

ordinary foundry practice, a pattern is used to form a cavity in sand into which the molten metal is poured, an individual mould being prepared for the casting required. On account of technical difficulties it is improbable that this method will ever be superseded for metals that have a high melting-point. Sand-castings, except for very rough work, must be finished, at all events so far as important dimensions are concerned, by machining, and the preparation of unmachined surfaces to a condition suitable to receive a deposit which afterwards has to be polished, is a costly business.

By the adoption of the die-casting process, finishing operations are almost entirely eliminated, but whereas for sand-casting the preparation of a suitable pattern is in most cases an expensive item, the provision of a suitable die is a considerable one and therefore cannot be considered as a paying proposition unless the cost can be spread over a large number of castings. In comparing the cost of the castings, it has to be remembered that a die-casting represents a finished machined part except perhaps for a tapping operation, so that where intricate machining operations have to be carried out on a part, the high cost of the work so involved might make a die more than worth while on a relatively small quantity.

Whilst aluminium and certain types of bronze can be die-cast, by far the greater proportion of die-castings are made in zinc-base alloy. This metal casts well and with a good finish. Earlier die-castings generally were confined to lightly stressed or purely ornamental parts that could be made from lead or tin-base alloys. This was on account of structural changes taking place in the then used zinc-base metals with ageing, resulting in serious changes in the formation of the castings or in disintegration.

Comparatively recent developments have led to the introduction of zinc-base alloys in which these serious defects have been overcome, and further, the mechanical and physical properties are such that castings made from them can satisfactorily replace those formerly made of iron or brass for certain purposes. These facts have probably had much to do with the popularisation of the process.

Die-casting Machines.—Machines for the purpose of die-casting follow more or less the same lines as regards the method used for filling the dies. A section of this portion of the machine is seen in Fig. 328. It will be seen that this consists of a gas-heated metal pot, arranged within which, in such a manner that it is almost completely submerged in molten metal, is a cylinder having a bottom outlet terminating in a "gooseneck." The

cylinder is fitted with a piston or plunger, and when this is at the top of its stroke a port is uncovered through which the molten metal flows into the cylinder and gooseneck.

The means vary on different machines for bringing the dies up to the nozzle, but when the dies are in position the plunger is depressed, either by a hand lever or air pressure, to force

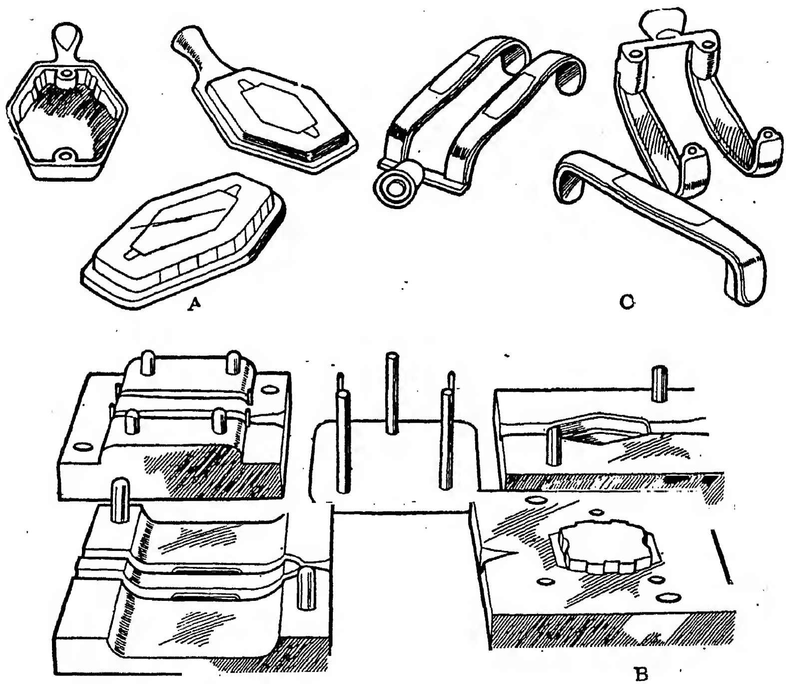


Fig. 329.—*Dies and the articles they produce.*

the molten metal into the die cavity. As the dies are comparatively cool, the solidification of the metal therein is almost instantaneous, so that the plunger can be raised again at once when the surplus metal in the nozzle drops back into the gooseneck. The die is then withdrawn from the nozzle, opened, and the casting ejected. With modern hand-operated or semi-automatic machines, the labour involved in performing the

sequence of operations has been reduced to a minimum, and the rate at which castings are produced must be seen to be believed.

As may be imagined, the most interesting part of die-casting lies in the dies themselves, for seldom are two jobs alike, and from a die-maker's point of view, each has to be dealt with in strict accordance with its peculiarities.

Die Design.—A die for producing a part full of cored holes, such as a carburettor body, must of necessity be a complicated piece of work, because for holes that are other than at right-angles to the parting line, core-drawing mechanism has to be incorporated. The principle on which the dies are made and operated will be best explained by taking simpler forms of castings as an example. The casting shown at A, Fig. 329, presents no difficulties so far as die-making is concerned, it being a really ideal job for die-casting methods. Perhaps it would be as well to explain that the dies are made in halves so that the casting can be removed, and it is known as the parting line where the faces of the half dies meet.

The die in which this particular part is made is shown separated at the right-hand side (B, Fig. 329). When together, the halves are kept in alignment by the locating pins protruding from the fixed half of the die. In this half is sunk an impression of the top portion of the casting. The raised part on the opposite half corresponds in reverse to the inside of the casting as seen in the top left-hand corner of Fig. 329, the blind holes in the boss centres being formed by slightly tapered pins fixed in the die. On the left-hand side of the dies is seen the runner, which matches up with the nozzle of the machine and through which the metal is admitted to the die-cavity. Leading from the impression in the fixed die, and seen at the right-hand side, is another shallow channel a few thousandths of an inch in depth. This is a vent through which the air in the cavity of the die is forced out by the incoming metal.

Removing the Finished Casting.—The lay-out of the die must be carried out in such a manner that the casting comes away on the movable half when the dies are opened. Usually, on account of shrinkage, or to the presence of cores, the casting is firmly attached to this half, and some means of pushing the casting off is required. It will be noticed that there are three holes, arranged triangular fashion, drilled through the face of the movable die. Two smaller holes are also in the die adjacent to the small core-pins. The purpose of these holes is to receive the pins set in the ejector plate seen on the left-hand side of the fixed die. This device functions as follows: when the dies are

opened, the travel of the movable die is continued until the plate reaches a stop, which pushes it forward. The small pins do the actual work of ejecting. The purpose of the larger pins is merely to return the small pins to a position flush with the surface of the die when ready for casting.

As previously mentioned, this die presents no real difficulties on account of the parting line of the casting being absolutely straight. It may be remarked that for the castings to be made with an absence of fin or "flash" at the parting line, the opposing faces of the die must fit perfectly and, therefore, flat surfaces are most easily produced with accuracy. The port-like openings in the sides of the castings call for careful work in the making of the die. These are provided by making the projecting portion on the face of the movable die to fit perfectly the sides of the opposite cavity in such a manner, of course, as not to prevent the die faces from bedding, the sides of the plug, as it were, being milled away in places to leave the bars between. When ejected from the die the castings appear as those shown in the top left-hand of Fig. 329, that is, with the runner included. The runner channel or gate in the die is cut fairly deep up to within about $\frac{1}{8}$ in. of the cavity, where the depth is reduced to approximately $\frac{1}{32}$ in. Thus, the unwanted metal is joined to the casting by a very thin section only and is, therefore, easily broken off.

Although still a simple proposition as a die-casting, the one shown in the bottom right-hand corner of Fig. 320 (C) presents more difficulties when the dies are considered. This will be apparent when the contour of the parting line of the dies (Fig. 329) is examined. These dies are made to cast two pieces at a time, the cavities being gated together. The ejector plate and pins are in the position that they occupy in the moving half of the die after a casting has been ejected. Fig. 329 clearly shows how the plate is returned by the four large pins as the dies are closed.

While it may be said that the examples chosen are not strictly accurate jobs, the products from the dies are absolutely uniform as regards dimensions. The surface finish of the casting depends upon the manner in which the die cavities are made free from scratches, and afterwards polished, plus the matter of keeping the molten metal at the correct temperature.

THE SPARK TEST FOR IRON AND STEEL

The spark test is a rough-and-ready test of composition, and cannot take the place of chemical analysis. A great advantage of this form of test is that it can be carried out on a billet, an ingot, a bar, a forging, or a finished piece.

The basis of the test is that different metals give off sparks, each having a different trajectory and form. Wrought or ingot iron will give off a little bundle of individual lines called a "spark picture." A 0·2 per cent. carbon steel will give a line of brighter colour and will throw off a series of fine branches from this line known as "forks," or "primary bursts." These are due to the presence of carbon. Wrought iron can readily be distinguished from carbon steel by means of the spark given off.

A few examples will serve to illustrate these facts. A (Fig. 329A) shows cast iron, which possesses a dull red, non-explosive spark that thickens towards the end. B shows wrought iron, whose spark is brighter, as indicated, and has a luminous extremity. If any traces of carbon are found in the iron, the extremity may reveal a burst or fork.

C shows mild steel. The thick, luminous, iron spark is broken up by the branching due to carbon. D shows a 0·80 per cent. carbon steel spark. The carbon branching occurs nearer to the grinding wheel. E shows a high-grade tool steel containing carbon. F is high-speed tool steel. An odd carbon spark or two are to be seen; the rest are modified by the other alloying elements. The sparks are of orange hue, and vary in brightness as they travel, giving the effect of an interrupted line; they have a more luminous tip.

G is high-manganese steel. In this case the spark is different from that of the carbon spark inasmuch as the explosive particle leaves the luminous line at right-angles, and the sub-division of explosions is also at 90 degrees, as against the 40–50 degrees of the carbon sparks at C. H is self-hardening Mushet steel. Here an odd manganese spark is visible, and the relatively high tungsten percentage appears to give discontinuity to the spark. Finally, I is a tungsten magnet steel. Here can be perceived the respective sparks of manganese, tungsten, and the like.

The volume of the sparks fluctuates with the pressure exerted on the steel, while the speed of travel of the sparks as flung off the wheel is governed by the peripheral speed of the grinding wheel.

A spark cabinet should be used for making this type of test. The steel should be held against the grinding wheel so that the spark stream is flung about a foot long in a horizontal direction and at a right-angle to the line of sight.

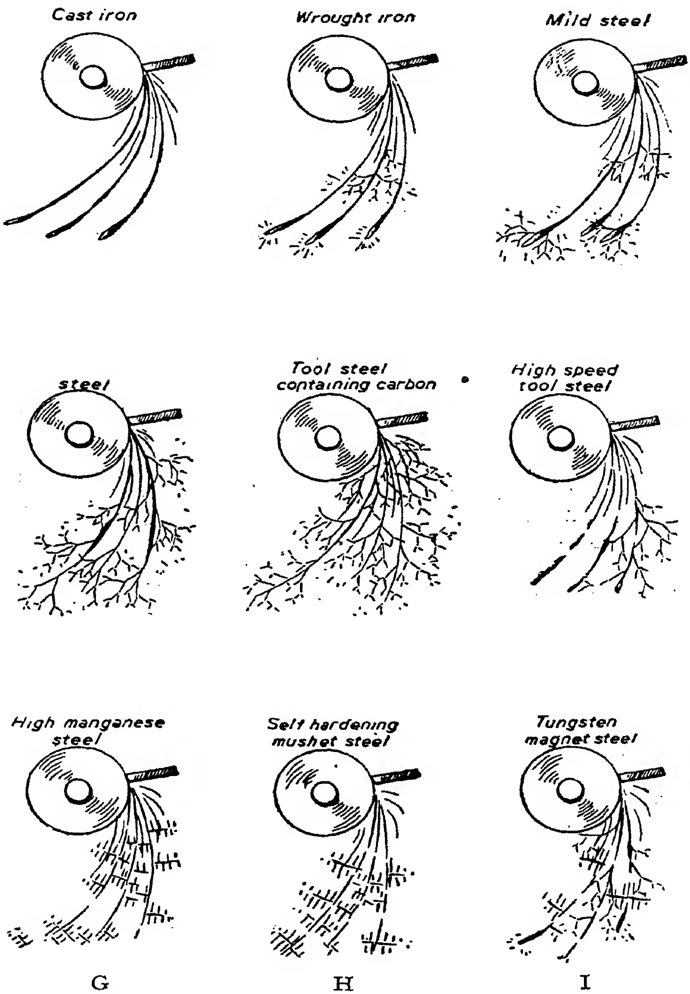


Fig. 329A.—*The spark test for iron and steel.*

OPTICAL MEASURING INSTRUMENTS

In the laboratory or gauge-room, where time is not so vital as in the factory and machine shop, extreme accuracy in measurement is obtained by means of optical instruments. The gauge-room in a large factory is generally a section of the inspection department, and although primarily concerned with the maintenance and periodical checking of the gauges used in production, equipment is also available which enables the first samples from new equipment, and cutting tools, such as hobs and gear cutters, to be checked both for size and profile of the cutting faces down to minute limits.

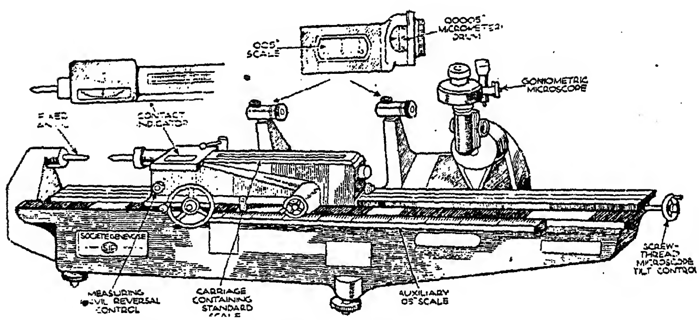


Fig. 330.—*A diagrammatic illustration of the S.I.P. measuring machine, showing points referred to in the text.*

The life of a gauge before re-checking is required varies according to the conditions of use, and the tolerances allowed on the component for which the gauge is employed. Gauges with tolerances of less than ·001 in., such as are frequently used for checking ground finishes, may be changed several times daily in a large factory where precision workmanship is the rule. On the other hand gauges for checking tolerances in the neighbourhood of ·01 in., which may perhaps be used only occasionally, possibly in conjunction with brass or other soft metals, will be recalled for checking only at intervals of six months.

As far as the first samples from new machine tools or new tool set-ups are concerned, it is, of course, of vital importance that

these should be submitted to the gauge-room in order that a report tabulating any errors in profile or departures from tolerance can be made out before the components go into quantity production. This applies, of course, not only to metal components, but also to stampings, pressings, pressure die castings, bakelite mouldings, and similar items, and in many instances a considerable degree of ingenuity and mathematical skill is required to check certain dimensions which may be clearly laid out on the drawing, but which are difficult of access on the actual part.

Universal Measuring Machine.—One of the best-known measuring instruments is the Zeiss universal measuring machine.

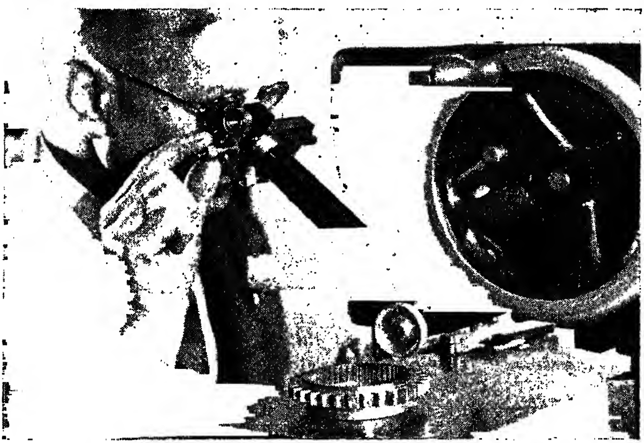


Fig. 331.—*The depth of the indentation made by the diamond in the metal is accurately measured with the aid of a microscope.*

This enables measurements to be taken to ·00001 in. The instrument is provided with microscope eyepieces, and in conjunction with an ingenious optical arrangement measurements of widths, depths, and angles can be carried out rapidly and accurately. The measurements are, moreover, taken directly by placing the part, such as a gauge, on a glass table beneath the microscope, allowing fine lines visible in the field of the microscope to be moved into register with the outline of the gauge.

Direct readings are obtained on scales, the divisions representing ·00005 in. (one-half of one ten-thousandth part of an

inch), and these divisions appear wide enough to be easily subdivided by the eye, enabling readings of one hundred-thousandth part of an inch to be obtained with comparative ease. Universal measuring machines of this type are installed, with other standard gauges, in a special room maintained at a constant temperature of 68° F.

Another recently introduced measuring machine is one of the well-known range of machines manufactured by the Société Genevoise.

The Jig Borer.—The jig borer is, of course, itself a measuring tool, since it enables the jig to be produced by actual measurements made on the machine, thus eliminating the previous marking off and setting up. It is, in fact, a scientific precision instrument which combines extreme accuracy with the necessarily robust construction to stand up to regular production work. The work table, which moves on slides finished to optical standards of accuracy, is controlled by self-correcting micrometer screws, provided with graduated drums on which readings can be taken by a microscope to ·00005 in. The machine is essentially universal in its use, and can be employed for side, face, and slot milling, and can thus be used for certain types of direct-production work, its self-measuring properties in this case eliminating the need for jigs.

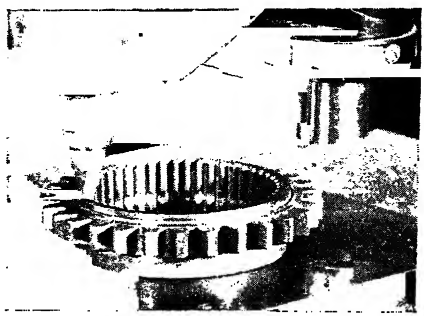


Fig. 332.—The diamond-pointed tool of an optical hardness tester being pressed into a sample pinion.

The S.I.P. Measuring Machine.—The measuring machine just referred to, however, is a specialised instrument, and replaces the former S.I.P. 500 and 1,000 models, and is known as type MUL 1,000. It can accommodate lengths up to 40·05 in., and also enables screw threads and diameters up to 5 in. to be measured, while with the aid of special attachments, spherical and flat standards, cylindrical and screw gauges, ring gauges, snap gauges, and contour gauges can be accurately checked.

In the illustration on page 284 it will be seen that the machine comprises a bed plate carrying a fixed measuring anvil at one

end and a traversing slide which carries a movable anvil, a contact indicator, a standard scale, and a micrometer microscope. This micrometer microscope deals with measurements up to 20 in., while a second micrometer microscope enables measurements of 20 to 40 in. to be read. Besides these microscopes there is a special microscope for measuring screw threads.

The Vee and flat carriage bearing surfaces are scraped and checked for accuracy by optical measurements. The carriage is a self-contained measuring unit containing a standard scale in an hermetically sealed space. The scale is "U" shaped and made from rust-proof steel alloy, having a coefficient of expansion of $11{\cdot}5 \times 10^{-6}$ ° C., rendering corrections for variations in room temperature unnecessary when dealing with steel or cast iron.

A clear idea of the action of the measuring machine can be obtained from a description of its use when taking an ordinary linear measurement. The test piece is mounted between the anvils, and a constant anvil pressure is ensured by the provision of a contact indicator, which must be set at zero. The approximate measurement to the nearest ·05 in. can be read off on the external scale. Accurate measurements are then taken by viewing the standard scale through the microscope eyepiece, each division seen representing ·005 in. Finally, a graduated micrometer drum on the microscope enables readings to be taken to ·00005 in.

The measuring instrument can be used as a comparator by first setting it to a master gauge, so that the contact pointer registers zero. By moving a small lever the movable anvil can be quickly withdrawn, allowing the master gauge to be replaced by the work or production gauge. Any difference in size will be directly indicated by variation from zero on the contact scale.

The scope of the machine is increased by the provision of tables, adjustable for height and fitted, if necessary, with centres, for measuring such items as a plug gauge. The action of the measuring anvil can be reversed by means of a lever, enabling feelers to press on the inside of a hollow bore, such as a ring gauge.

Finally, the goniometric microscope for the examination of screw threads can be tilted by means of a hand wheel up to 10° to suit the mean helix angle of the thread. Vernier graduations enable readings to be taken to within five minutes, while a special glass table enables this microscope to be used for measuring small tools, profile gauges, dies, punches, etc.

The Optical Projection System.—The normal types of profile gauge will, of course, be familiar to most readers, and in the gauge-room the problem of checking them arises. Linear

and angular measurements can be checked on one of the measuring machines just described, but probably the most satisfactory method of checking the contour of the gauge is to project a greatly enlarged silhouette of it on to a table.

This also applies to such parts as small pinions, spindles, spherical seatings, and form gauges which cannot be measured easily by ordinary instruments, while a section of the profile of the teeth of a gear cutter or hob, or the profile of a screw thread, can be checked against master drawings in the same manner. There are several well-known examples of this equipment, among them the Zeiss projector and the Taylor-Hobson equipment.

In some cases the projector, lens and mirrors are so arranged that the image of a small part is thrown on to a screen immediately behind the projector, but where larger components necessitating a considerable degree of enlargement are to be dealt with the projector is generally arranged outside a light-proof cabinet. The image is thrown by mirrors to the top of the cabinet.

Testing for Hardness.—A further application of optical measurement is found in the gauge-room or laboratory when testing sample components for hardness. The normal hardness indicator, such as the Rockwell design, in which a diamond point impelled by a known weight " pricks " the metal of the part, the depth of impression, being recorded by a sensitive dial gauge, is accurate enough for normal production work, and enables thousands of small parts to be tested in rapid succession.

In the laboratory a more accurate version of this principle enables the exact depth of the indentation to be measured with microscopic accuracy. The diamond is forced into the surface of the metal in much the same manner as with the ordinary hardness tester, but the operator then observes the depression through a microscope ocular. The knife edges which appear as shadows on each side of the field of the microscope can then be adjusted inwards until they just touch the corners of the diamond-shaped impression.

Optical Flats.—While dealing with optical standards of accuracy, the tolerances observed when checking the plane surfaces of gauges are worth mentioning. These surfaces are checked by optical apparatus which makes use of " optical flats." These plates of glass have surfaces ground plane and parallel to limits of ·000005 in. (five one-millionth parts of an inch), and to tolerances of ·00001 in. for thickness. With the aid of optical equipment it is possible to determine the heights of adjacent areas on the surface of the gauge to be checked in " steps " of ·000015 in. (fifteen one-millionth parts of an inch).

MILLING PRACTICE

Milling is the most versatile method of cutting metal, and nearly every operation which can be done on any kind of machine tool is also possible by this system. Alternative methods of milling occur in many sorts of work, the choice depending on the class of machine in use, or how access may be had to the surfaces. It will be interesting to make a concise survey of the various applications of the process, extending from simple to complicated examples. There is often a difference in the manner of milling small and large areas, where the time occupied in doing the former is so brief that a form of procedure may be adopted which might not be economical for the latter.

Plane Surfaces.—Ordinary flat faces unobstructed by projections and of considerable width can be machined either by slab or by face mills, the latter in heaviest practice being run in rotary planers. The system is suitable for ending columns, girders, and feet of large castings of various sorts, but lacks the ability to deal with different levels, angular portions, or other profiles combined with the plane sections; the slab mills will undertake anything in this direction by the stringing of suitable units along the arbor, and great width is usually no objection because intermediate arbor supports may generally be interposed at one or more places to prevent deflection. Heavy cutting is facilitated by fitting inserted teeth to break up the chips and making the inclination a rather quick spiral, units being opposed as to handing in order to eliminate end thrust. It is best not to make cutters too long, but preferably to build them up; then changes can be readily made to suit different jobs, and any damage done to teeth is more easily attended to.

The particular advantage of the end-milling method (apart from the heavy rotary machine system) is that shoulders anywhere can be worked up to, upstanding parts skirted around, and sides also milled—all with the same cutter. The rate of metal removal may not always be as fast as with the cylindrical cutter, such as when cutting grooves and keyways. There is a principle employed in some cases when a keyway is required to have the ends finished up squarely, the machine carrying two cutters, one of disc type to mill the groove rapidly, the other of end style just to finish the terminations.

On both the slabbing and the end-milling principle large plano-type machines are constructed with duplex rails, front and back of the standards; a string of castings may be roughed and

finished at one pass by the respective sets of mills in heads on the two rails, or in heads sliding upon the uprights as well.

An unusual method of surfacing is to be noted, on a machine for milling the semicircular flanges at the end of cylinder blocks. The cutter spindles, for roughing and finishing, are mounted in a cylindrical drum which rotates and thus traverses the mills in a circular path across the work. The finishing cutter is adjustable axially in relation to the finishing one. When the drum has completed a revolution, both cutters have passed across the surface. The drum lies horizontally and the cylinder block is held in a fixture upon the horizontal table.

Continuous Milling.—A fast production rate is obtainable by the continuous system, applicable to various plane surfaces, external and internal; certain shapes cannot be done in this manner, but a vast number can, and the magnitude of the operation depends on size of units and numbers dealt with. Small and medium sizes are handled on a rotary attachment on the table of an ordinary miller, otherwise regular machines for continuous milling have the table built integrally, giving substantial support for fixtures and pieces. In one design the table is tilted to an angle of about 15 degrees, more easily to swill away the chips.

The number of fixtures grouped around the table depends on the size of articles, or how they have to lie, and unloading and clamping proceed as the table revolves. The utmost cutting effect is ensured by placing the units as closely together as possible, thus not leaving wasteful gaps, and by intergrouping them in some instances to get more on the table. The diameter of the face mill may also be enough to cover two or more components at once. Furthermore, quick-acting clamps facilitate the release and regripping, and automatic clamps carry the matter a stage farther. Sometimes automatic ejection is also arranged, such as for screws or pins inserted in holes in the fixture, a spring or cam mechanism coming into action after the piece has gone well past the mill.

For a great many subjects it is sufficient to mill over at one pass, either because the finish is good enough or further treatment (such as grinding) follows, but many machines are built to operate roughing and finishing cutters, or sets of these for large objects. In the latter design the duplex spindle heads are mounted on rails over the table, and there may be as many as eight spindles.

The greatest production is attained on the double-ended horizontal drum machines. The castings or forgings are clamped

by hand or automatically in fixtures on the drum, and spindles in the standards at each end perform the roughing and finishing

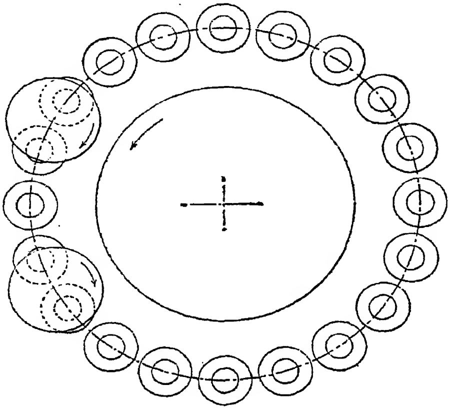


Fig. 333.—*Arrangement of roughing and finishing cutters for a drum-type of continuous machine.*

cuts. Frail castings are sometimes acted on by more cutters, such as four for roughing and four for finishing, thus enabling a good rate of feed to be given without risking accuracy. Fig. 333

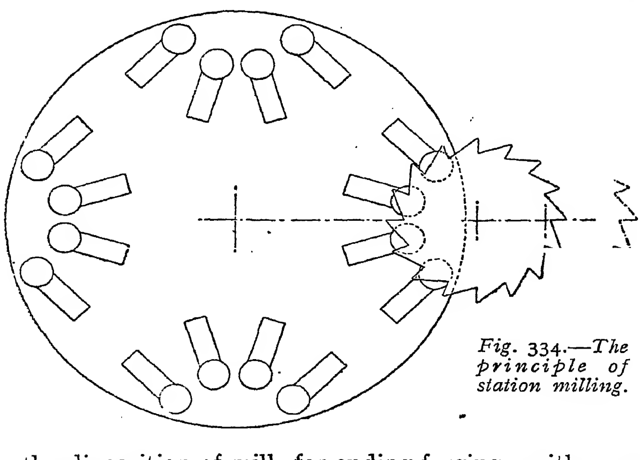


Fig. 334.—*The principle of station milling.*

shows the disposition of mills for ending forgings, with roughing and finishing cutters at each standard. Frequently two shorter

parts occupy the width of a drum at each station, being of similar kind; or half the width of the drum will hold a circle of components pointing one way to finish the feet, and they are next transferred to the other half to do the tops. Staggered formation is chosen in such examples so as to make the total cut as continuous as possible.

Station Milling.—There are two reasons why the continuous principle may not be applied. One is that the work-pieces cannot always be compactly spaced in a manner to avoid idle travel between cuts, the other that the shape will require a direct infeed not practicable by the continuous method. Hence the station

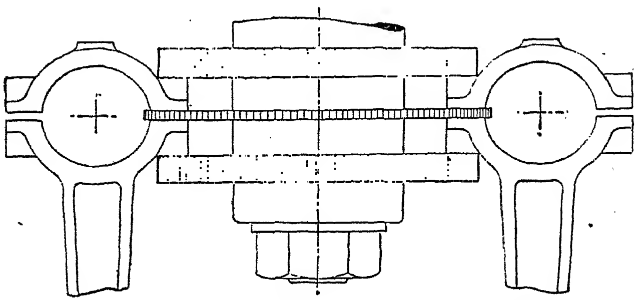


Fig. 335.—Station milling on adjacent components.

mode is employed, and the change of work units takes place either by a rotative indexing or reciprocation, according to the type of machine.

Single parts, or groups closely packed, are fed by the table movement, or the spindle column is fed, the return stroke being just sufficient to clear the cutter. The layout is apparent from Fig. 334. Either top faces, or top and bottom, as well as inside faces, can be milled. Some articles are mounted in pairs for the mill to pass between them and perform an operation at the flank of each, an example of this being shown in Fig. 335, where the side of each connecting-rod is slitted and straddle-milled on the bolt lugs.

The reciprocating idea is a form of station milling, using single or multiple-hold fixtures toward each end of the table, which feeds to and fro automatically and permits unloading to be effected at one fixture. Various arrangements of mills are utilised; face, straddle, slitting, and gang. Sometimes the

spindle does not need reverse, in other cases it does, while another variant consists in running two spindles, revolving in

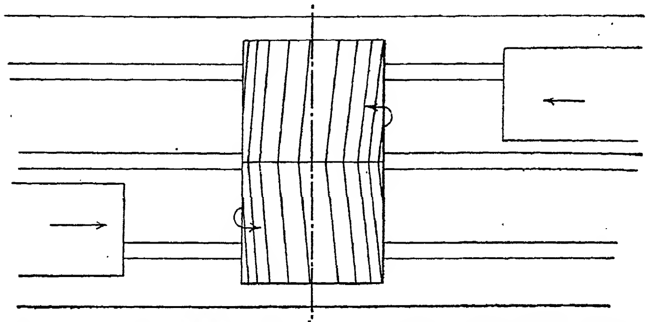


Fig. 336.—*Spindle reversal system for giving cutting and loading stations.*

opposite directions so that cutting is always downward on to the table. Fig. 336 illustrates the reversal scheme. In contrast to this simple set-up, Fig. 337 may be studied as a specimen of an

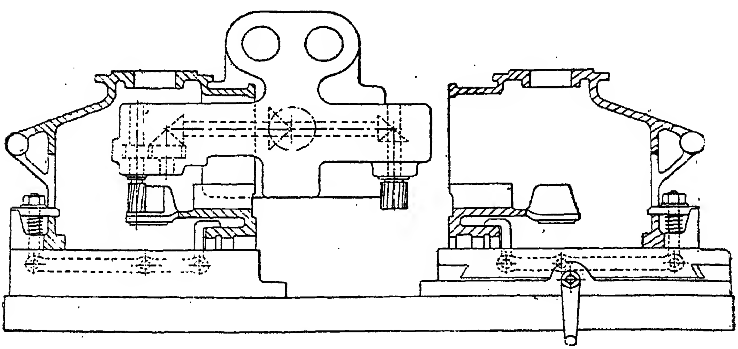


Fig. 337.—*Special set-up for two operations on casting.*

attachment with arms carrying three cutter-spindles to reach into the bosses of the casting. The fixture at the right has a cross-adjustment to enable the large cutter to go down one side of the

slot at the mouth of the casting and back on the opposite side, milling the bottom of the slot as well. The two small mills finish the sides of the inner boss. The casting has to be transferred from one fixture to the other to carry out these operations, but milling proceeds whilst the one fixture is being stripped and reloaded.

Another kind of station milling employs an indexing table that slews round, after the table has made its quick return, and presents the work in the fixture at the opposite end, whereupon the rapid power traverse goes on, then changes to feed rate. This comparatively simple device possesses great possibilities for all sorts of single and multiple holding and with plain or complicated cutter outfits.

Form and Gang Milling.—One of the chief advantages of the milling process, which was its most appreciated feature in the early days as applied to small-arms and sewing-machine manufacture, is that of being able to cut contours of all kinds on large numbers of parts uniformly. The principal development is that of heavy milling and the utilisation of several spindles to deal with surfaces at different levels. It may be easier to apply single mills from side spindles than to attempt to cover the width of a casting by a long arbor equipped with small and large units, and adjustments are more readily made by following this method. The precise choice of a form mill may depend on length and the number of components to be done. For moderate quantities, or where alterations might have to be made at any time, it is preferable to build up straight, angular, and curved outlines by units, but the more expensive solid mills are often made when many thousands of pieces have to be handled. There is no fixed policy, however, as regards such practice. When sharpening would alter the width between faces it is essential to include separate cutters with loose or adjustable spacing washers between them.

The procedure in form and gang milling the more complex outlines depends on the degree of accuracy desired and the relative importance of the respective sections. Roughing may be carried out all over, or on certain areas; alternatively, the finishing set will miss some surfaces. The nature of a subsequent process, such as grinding, often determines the question. Fig. 338 shows roughing and finishing sets for a bed, the vees being only topped off by the first cutting and the edges of the shears finished, while the flat surfaces at the right are dealt with separately. It does not follow that the finishing cuts are taken directly after the roughing in point of time, because a period of seasoning is often allowed for castings to settle into practically permanent form.

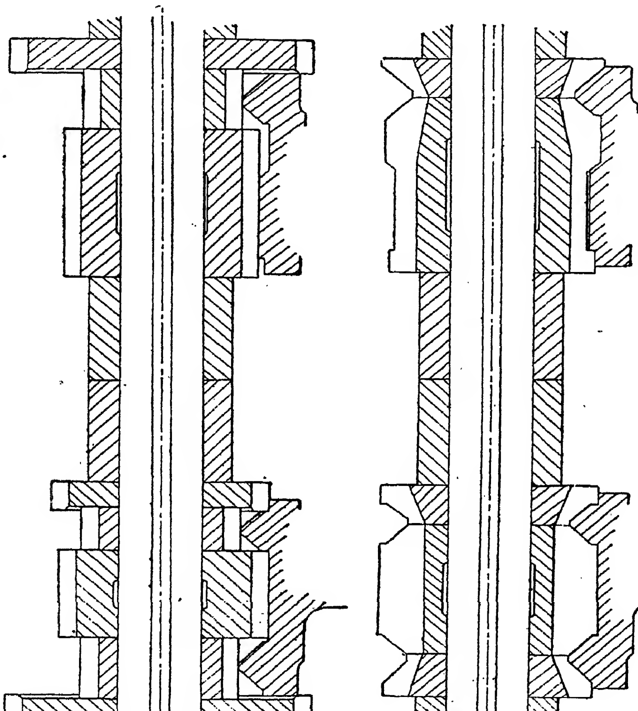


Fig. 338.—*Roughing and finishing procedure with gang mills.*

Many castings have to be roughed out on all the machinable faces so as to relieve the internal strains, because milling off, say, a base and leaving the top for a while does not meet the case. This is especially true of the thinner examples.

If the width of a subject is moderate, output may be increased by duplicating the cutter gangs and using two fixtures. Roughing and finishing are also effected on some occasions, the job being shifted laterally by the cross-saddle adjustment after passing under the roughing mills, to come under the other gang. Another notion, which keeps up a regular flow of pieces from the machine, consists in doing all the milling on the various areas by

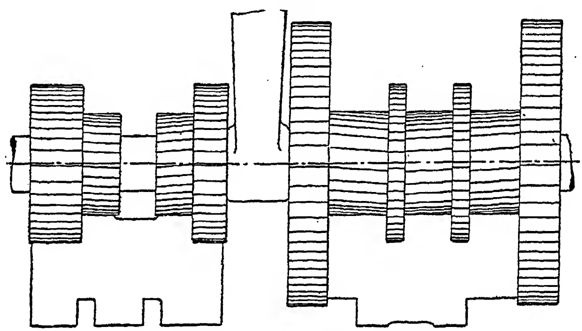


Fig. 339.—*Maintaining work flow by performing all cuts on the piece on one machine.*

having two fixtures and gangs, transferring the part from one fixture to the other. Fig. 339 shows an example. Consequently the one operator is not hampered by a pile of half-finished castings and the next department is never kept waiting. The swivel table previously mentioned becomes of value in getting out objects of medium size, with the use of differing sets of cutters on the same arbor; at one traverse flats, grooves, vees, etc., are finished, after which the table is turned round and advanced to bring the other batch under the other mills.

The plano-millers provide means of machining innumerable shapes other than by arbor gangs, which are unable to cope with a good many forms, and practice may include gangs in collaboration with side heads, or everything may be carried on by vertical, horizontal, and angular spindles, each driving one or two cutters. The alternative is possible of tooling angular faces either by angular mills or of applying ordinary face cutters in inclined

spindles, the choice depending on the design of machine and how the several cutting units happen to come in mutual relation-

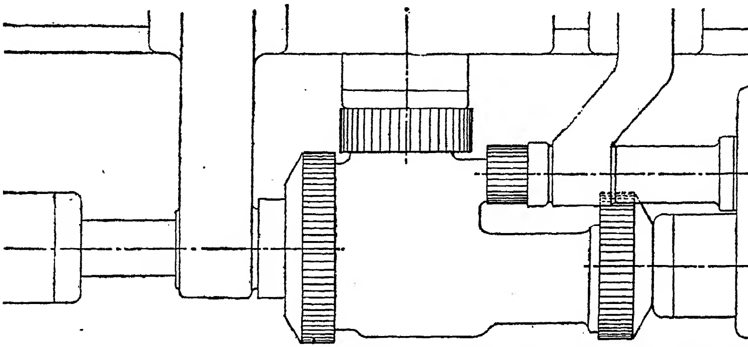
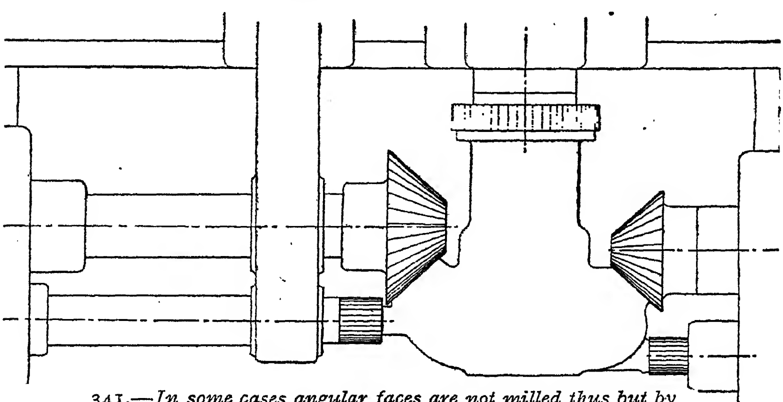


Fig. 340.—Plano-miller set-up, including special arbor stays and an auxiliary spindle.

ship. It is cheaper to utilise face mills, disposed angularly as necessary, than to make special angle cutters of large diameter, but the problem is a matter of how long their services are required.



341.—*In some cases angular faces are not milled thus but by angularly set spindles and flat face mills.*

Figs. 340 and 341 afford specimens of gang work, and in each there is a supplementary spindle. As regards vertical spindles

on the cross-rail, variations comprise the running of a small or large face mill in a fixed position, or its feed or transfer laterally to cover different spots ; also the mounting of two or three vertical spindles for face or edge mills. They will not perhaps operate continually, but one or two lie idle ready for another piece of work to go on the table, or for the same piece to be inverted. A right-angle head supplies a valuable aid when completing castings at one setting ; the spindle axis comes in line with the table. Hence, a recess, such as for a bearing or face, or an opening at

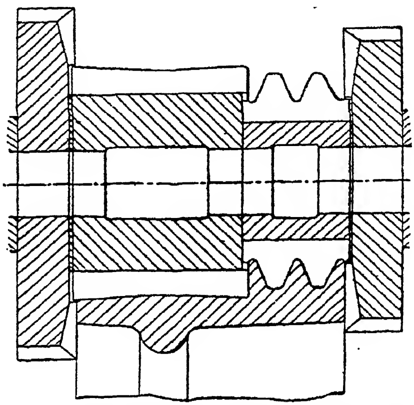


Fig. 342.—Showing how a complicated profile can be milled faster than it can be turned.

right angles across a frame, is machined without disturbing the position.

Circular Milling.—Advantages accrue from milling, instead of turning, on a varied range of jobs, the cutting is often much faster, relatively flimsy rims are easier to deal with successfully, profiles are completed of any outline with form mills, and segments of circles can be milled with less trouble as to chucking and no difficulty in tool action. A great amount of circular work is accomplished on ordinary millers, but the heavier classes are more economically handled on the circular millers. The special merit of being able to form a periphery and sides on a section that would not withstand the action of a forming tool in a lathe is important : spur, bevel, worm, and chain-wheel rims are thus machined, also pulley rims for flat or vee belts, a combination of

these being shown in Fig. 342. Segmental curves are good subjects for milling, as the feed rate can be enhanced at the intervals between them by an arrangement of control dogs. Internal work likewise is frequently more easy to accomplish by milling than on the lathe.

Cam Cutting.—The several kinds of cam extant demand different treatment, the peripheral type usually being milled with the help of a former device controlling the action so as to reproduce the same shape as that of the former. A spiral head may also be utilised to produce a regular spiral or a varied contour according to the mode of manipulation, this constituting a favoured method when producing cams for automatic screw machines. By means of an attachment to a milling machine,

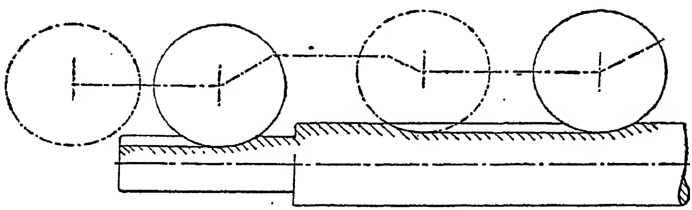


Fig. 343.—Diagram showing how cam and roller motion, causing the knee and table to rise and fall, enable the miller to be used for splining four shafts held side by side.

peripheral, face, or cylindrical cams may be cut. A hand-actuated worm gear turns the cam blank held in the attachment and a master cam is attached to the worm wheel. This controls rack and pinion mechanism to give the required lead and shape.

Profiling.—This form of cutting does not depend upon the shape of the mill, but, like cam cutting, is generally done from a master shape, against which a tracer-pin or roller contacts and controls the path of a table or a spindle saddle. There are various ways of producing the result, the original type of machine having a spindle saddle with roller mounting to move easily along the cross-rail, and a tracer-pin adjacent to the spindle. The work and copy go on the table, and the pin maintains contact against the varying contour of the copy by weight or hand feed.

In the single-standard style of vertical miller the profiling mechanism comprises a former on the table, underneath the work, and a roller in the arbor support beneath the cutter, the table being freed from its feed screw and pressed along by weights. Another scheme, on horizontal machines of the Lincoln pattern

and plano-millers, is to let the cross-rail rise and fall under the coercion of a profile strip fastened down on the table. This is combined with a special hydraulic valve control, the roller of the hydraulic tracer valve following the sheet-metal former. Diverse arrangements for the smaller productions are rigged up on the plain or universal millers, to coerce the table motion or that of a fixture. One set-up, for instance, has a hinged work-platen that rises and falls as the table feeds along, a former being located under the platen, and a fixed pin and roller affecting the movement, which results in a curve being formed on the piece.

Automatic Cam Control.—Although not strictly profiling, a special motion is sometimes imparted to a table for obtaining different settings which would otherwise have to be made by hand. This time-saving action is exemplified, as a case in point, by Fig. 343, from an Archdale horizontal equipped for splining four shafts held side by side in a fixture. Cam-and-roller motion causes the knee and table to rise and fall so as to evolve the cycle depicted in the diagram.

Spiral Milling.—This, which includes long spirals (as for twist drills) and the more ordinary threads for screws and worms, may be performed either on a universal machine with spiral head, on a regular thread or worm miller, or on a special-purpose type, such as that constructed solely for twist-drill manufacture. Ordinary screws which were formerly cut on lathes are produced in great numbers by milling, and the various kinds of thread can be generated with cutters of suitable profile, according to whether the thread is vee, Acme, square, buttress, knuckle, wood, or any special style. The longer screws may be milled by a single-tooth cutter, or shorter screws may be completed at one revolution from a multiple-thread cutter. The latter is also employed sometimes for cutting double or triple-thread worms, provided that the helix angle is not too great. The completion of the revolution is a matter for automatic control, the action being arrested as the work makes very slightly more than the full rotation. For the most accurate requirements the teeth should be precision ground all over to remove any errors arising from the hardening process.

MULTI-TURNING PRACTICE

Concentrated attack upon a piece of work is the modern method of tooling, and it is nowhere more evident than in turning. The

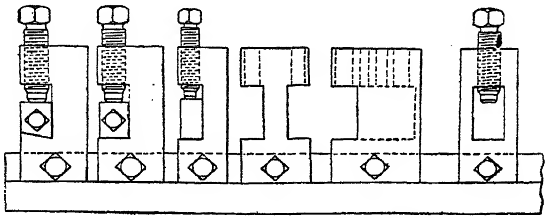


Fig. 344.—*Tool blocks used on multi-turning lathe.*

germs of such practice arose long ago in lathes designed for shafts, axles, wheels, pulleys, etc. with slide rests at front and rear, and sometimes a boring-rest added. Then the development of the capstan and turret lathes, auto-turning lathes, and automatic screw machines, multi-tool lathes, and production boring

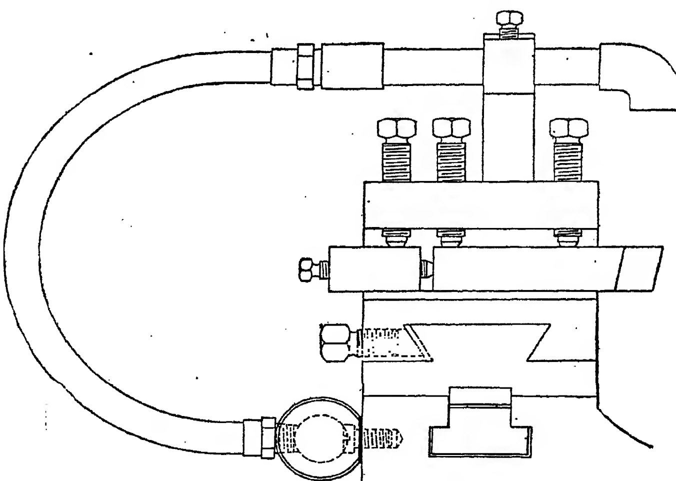
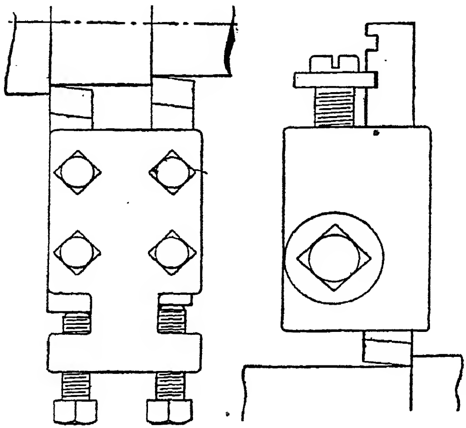


Fig. 345.—*Arrangement of toolholder adjusting screw and coolant supply.*



346.—*Unit-blocks for assembling into sets.*

mills and allied types gave full scope for intensive cutting, using several tools grouped closely together, and sets of such all acting simultaneously, as far as practicable. Limitations occur, from the strength of a casting or forging, the possibility of finding room for more than one holder and tools to get to positions, and the necessity of allowing for heat dissipation, or roughing and finishing cuts. The advantage of balanced pressures is notable in many cases, tending to render chucking grip more secure and concentricities surer. Pilotage assists greatly in many multi settings, so that the thrust against a number of cutting edges is resisted positively. The line of application varies considerably from the normal horizontal—tools may lie overhead, beneath, at an angle, swing on a radial arm, or be controlled by a profiling mechanism to any angular or curved path.

Tool-holding Principles.—The aim is always to make a tool as simply as possible, with the least liability to breakdown, and maximum ease of sharpening; and the holding schemes should also be simple and strong. Exceptions arise where this may not be feasible, owing to the complicated nature of the machining. But risks of undue wear or damage to expensive tools are often reduced by giving a roughing

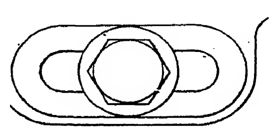


Fig. 347.—*Cross-slide with convenient adjustment of blocks.*

cut with a different sort of tool, leaving the finishing of the outlines to the more delicate finisher. For example, some con-

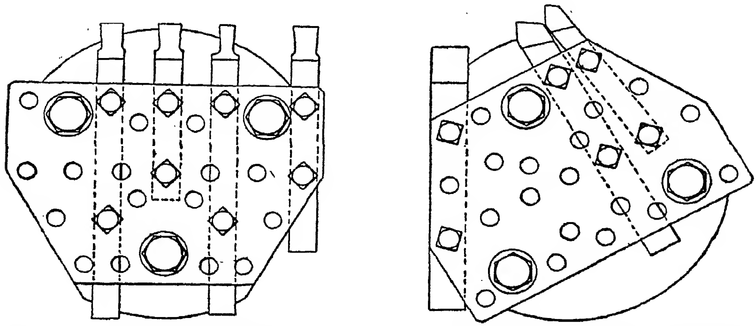


Fig. 348.—*This block will hold tools in various positions, and can be adjusted to different angles.*

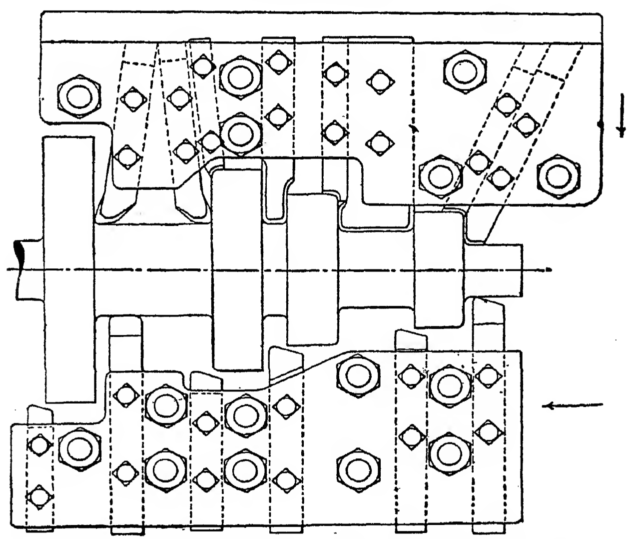
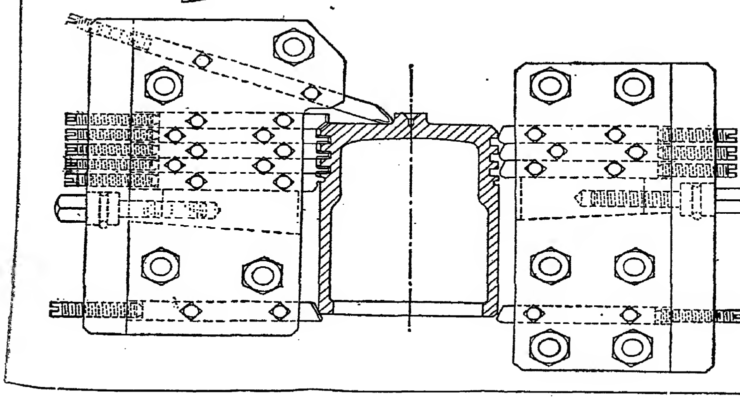


Fig. 349.—*Here the blocks and plates are specially shaped for one piece of work.*

tours are roughed out by a single-point tool controlled from a profiling device, and finished perfectly by a form tool. Many



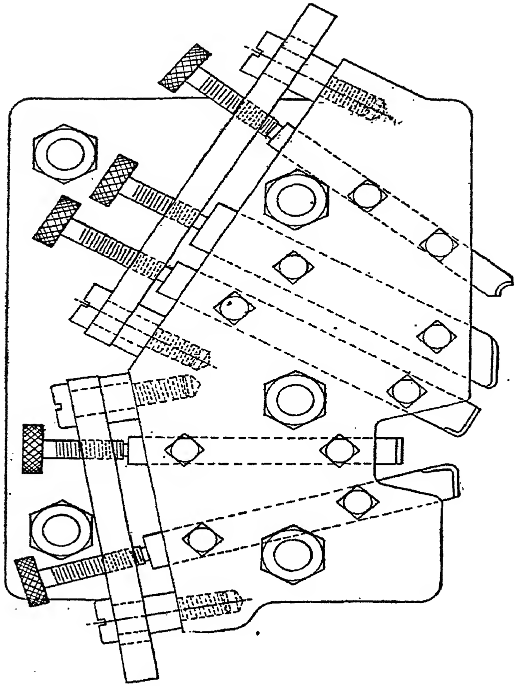


Fig. 350 (*Left*).—*Separate screw adjustments, and wedges for consolidating grip on tools.*

Fig. 351 (*Right*).—*The plates carrying the adjusting screws throw back for instant withdrawal of tools.*

shapes can also be partially done with simple slide-fed tools which break down the bulk of the outline, leaving very little

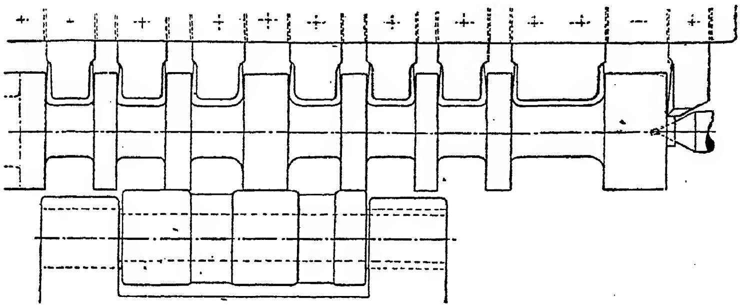
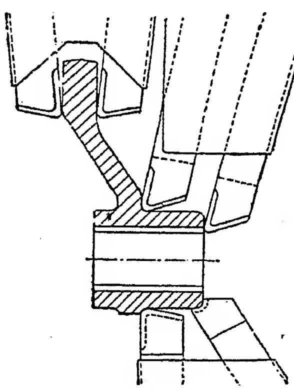
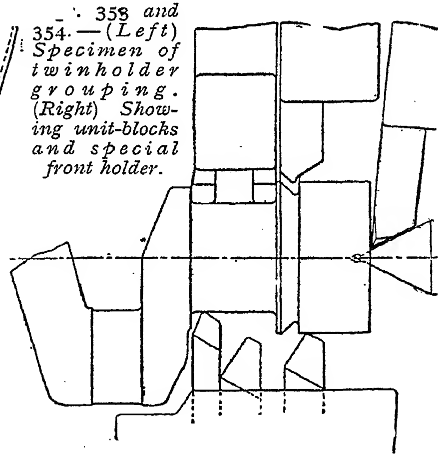


Fig. 352.—Example of strenuous forming which needs roller support.



353 *and* 354.—(*Left*) *Specimen of twinholder grouping.* (*Right*) *Showing unit-blocks and special front holder.*



completion for one or more finishers. Fragile tools unavoidably necessary (as for grooving) should be accurately ground and fitted to the holder, and clamped firmly without local pressure being given. Minimum projection must be allowed, and under-

supports provided when snapping off is a danger. Spindles, chucking arrangements, and tool-slides should be guarded against deflection and chatter.

Unit-Blocks and Group-Holders.—A main difference in multiple tool mountings is whether the set is composed of unit-holders arranged together, or whether several tools fit into a block of standard or special shape. It is difficult to specify

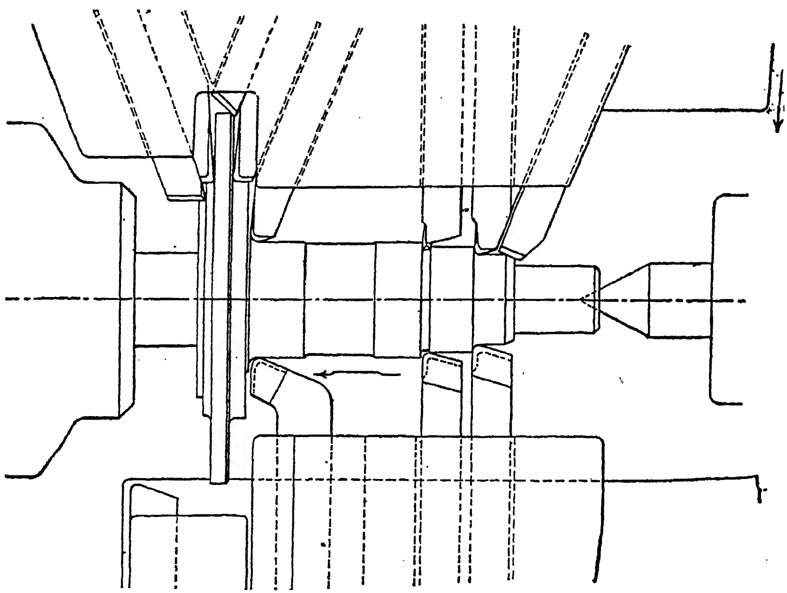


Fig. 355.—Special main blocks and one standard holder.

either system as being the more suitable, because some components are turned by unit-holder set-ups, while another man would have the group-block method. It depends on the choice of equipment at hand, the number of operations, and the quantity produced. A small batch would not pay for making special holders. Other complications occur, such as whether taper-turning, forming, or profiling have to be done alongside the ordinary turning, grooving, facing, chamfering, and other tools. Furthermore, in the endeavour to do as much removal as possible

in a given time, very close approach may be necessary between respective holders on slides, arms, turrets, auxiliary slides, etc., thus necessitating close forming of the holder bodies to receive the tools without fouling the other items of the outfit. Frequently also the mode of clamping the tools may have to be specially modified to keep screws or clamps out of the way.

Another aspect of the unit-block question relates to submountings, that is, when it is required to execute a more delicate operation, as putting a set of grooves in a piston, for which a special holder is prepared, and afterwards stored away intact ready for another order. It may be employed along with individually set tools for other cuts, as facing and chamfering, and the special holder is the only part of the equipment that cannot be used for general service. Also circumstances will be met with involving the inclusion of one or more special holders furnished with fine adjustments, by graduations, vernier, or micrometer dial, while the other holders have nothing or only plain thrust screws.

Swarf Clearance.—In intensive cutting it is important to consider free escape for the chips, especially when they might be of a long curling nature, apt to encumber tools and holders. In the first place the machine must be designed with capacious outlets, so that no initial hindrance is caused; then the tool fastenings should not stand in the way when a less obtrusive scheme is possible, and bodies of holders must present as streamlined an outline as practicable. An inclined or overhead position often helps in the more complicated machines, the cuttings falling away from the tools and holders. Strong coolant pressure is another agent which facilitates swarf flow. Finally the tools can be made to prevent formation of long curling chips, or to break them up into short, easily disposed-of pieces.

Front and Rear Mountings.—There are diverse ways of using front and rear tools, depending on the kind of work, or the class of machine employed. Sometimes either disposition may be run in a similar manner (subject to the difference of inversion of the tools), that is, turning, grooving, forming, chamfering, cutting off and so on might be effected from front or rear without making any difference to the results. Or a front or rear attitude will often be the better choice for reasons of fast working, or obtaining higher finish. These statements require modification when considering some of the production lathes, in which the principle is as far as possible to do the longitudinal or traverse feeds from the front saddle, and the cross feeds, for facing, necking, forming, etc., from the rear. Exceptions of course occur,

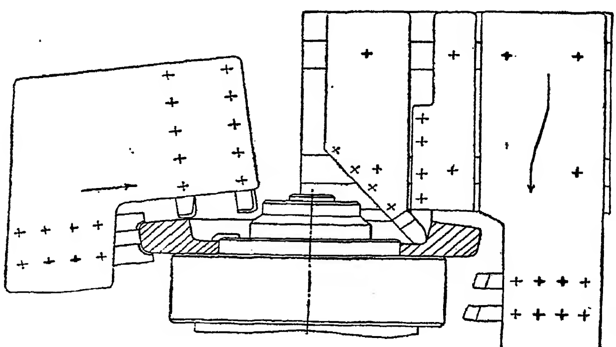


Fig. 356.—This outfit includes twin roughing and finishing tools.

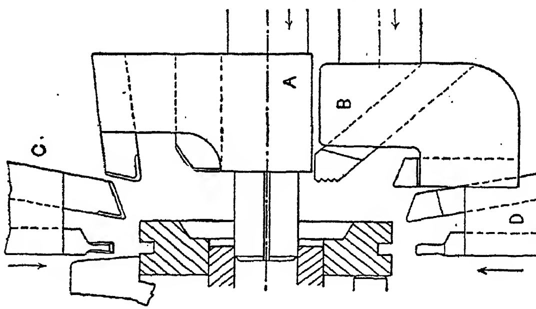


Fig. 357.—Roughing and finishing sets are also applied to this tooling.

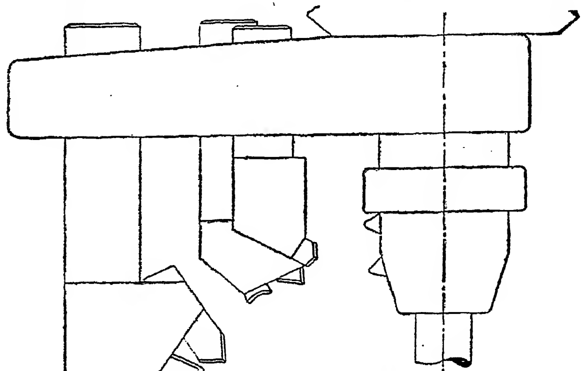


Fig. 358.—Instance of multi-tool bar layout for turret lathe.

and there are problems of extra slides or arms, and auxiliary movements to consider.

Rear mounting may provide a better finish in capstan and turret work when forming tools are being used, because of the slight give of the slides, and elasticity of the tool-holder. On occasion rough forming might be performed from the front and finish from the back, the first perhaps not to the complete contour, but more of a breaking-down process.

Roughing and Finishing.—One of the great merits of multi-tooling is that of convenient roughing and finishing of many parts at one chucking. The alternatives are to rough with one slide movement, and finish with that of another, often of a different character ; or to set close together tools in one holder which follow in succession along, or across, or on a bevel. According to the nature of the work-piece the tools may be nearly similar in shape, or the first will be serrated for chip-breaking and attack scale more readily.

Reducing Length of Traverse.—Another time-saving feature consists in setting two tools to complete a length with half its distance in feed, or three or four tools spaced to follow this idea still more effectually. The timing in relation to other cuts is thereby advantageous.

Speed and Feed Changes.—In order to get the best and quickest results, hand or automatic changes are available for instant application. Roughing or finishing passes can be done at the most suitable speeds, or feeds may be altered as well. Broad faces requiring slower rate are also properly dealt with, or a tool travelling from the edge of a flange to some way inwards can have the correct surface speed imparted by a change after it has left the edge a while.

Automatic Tool Relief.—Cam-actuated mechanisms provide for tool relief in some production lathes, to avoid scoring on the return stroke. The action is also important when using multiple tools as mentioned above to reduce length of traverse, the tool pressure being faded out when the cuts start to overlap.

Simple Tool-Blocks.—The plainest kind of block, whether fitted to a lathe saddle or arm, a cross-slide, or a box-tool, is of rectangular form, or sometimes bevelled off at a corner for clearance in relation to another part. Swivel may be a mode of angling the tool, but often the block is cut with angular slots instead. Various requirements of normal single-tool blocks, thin blocks, and those for two or three tools go to make up a set, while taper-turning or profile-tool holders are special. Fig. 344 gives the simple blocks of a Fay lathe, variations on open and

closed types, the fifth from the left being with angled slot, which is also made the opposite handing. All the blocks will also fit the back facing arm. For end adjustment and resisting thrust a pad with screw, Fig. 345, can be held. Coolant supply comes from the distributor attached to the back as seen, and the flexible piping is connected by a taper union to a hole, a series being tapped in the distributor, and those not required closed by plugs. For taper turning or profiling while the carriage is turning straight a taper turning block is supplied moving slidably in the holder and having a former bar cut to the taper or profile. Different kinds of tool rams are available, depending on whether the set-up of the other tools requires a right- or left-hand placing, or a tool located at 45°.

In box-tools, and many blocks for various sorts of machines a favoured mode of adjustment is by a screw notched into the tool, two or more notches affording range for compensation for wear, Fig. 346. Twin holding likewise shown is largely adopted for turning shouldered parts, or roughing and finishing. In box-tools, and many cross-slide tools the same result is procured by individual blocks regulated along a slideway, Fig. 347.

Multiple Tool Blocks.—These present great variety—square, oblong, angular, curved, fixed or swivel, and with or without end adjustment to the tools. The fastening is generally by means of headed or hollow screws, but wedges may be added in some examples. Swivel motion is the idea in one class of holder for facing and forming, generally mounted on a turret lathe cross-slide. The top plate is placed on studs with height collars, and an assortment of tapped holes gives choice of locations for the binding screws. Two to six shanks may be assembled, to point straightforward or at angles, not necessarily all similar. Fig. 348 illustrates two of the numerous dispositions. The same sort of thing occurs in rectangular form, without any angular alterations, and is often less trouble to set up than unit blocks. Moreover, when production is on a big scale the tools may not be disturbed, but the block is taken away and put in store intact.

Contoured Blocks.—When the straight-front holders are unsuitable because of the radical differences in diameters at various points, a shaped block and top plate must be designed. This will either be suited only for one piece of work, or supplementary tapped holes be included so that certain modifications are possible to emplace some of the tools to right or left, or add extra ones for turning, facing, or chamfering, etc. Thus differences in the same general outline are catered for ; or changes in design after a while do not mean new blocks. Fig. 349 is an

outfit for front turning and rear facing and forming, the profiles following the work plan rather closely.

Tail adjustment by screws is arranged in independent fashion, or from a rear plate. The first-named style is like that in Figs. 345 and 346, or a sort of poppet head is set by its stem in the block behind the tool, and carries the adjusting screw; by swivelling the poppet the screw tip can be brought into line with angularly-disposed tools. The rear plate is a favourite method, as screws can be scattered about freely, straight or diverging, and thin blades for grooving can have little screws closely pitched. Setting of a batch of tools is facilitated by fastening a gauge to the front of the tool block and feeding up each blade until it makes contact with the gauge. Firmness is sometimes assured by the device in Fig. 350, a wedge jammed against the nest of tools. Another way of grooving is to use a circular hob-shaped cutter, with rings of teeth upstanding, and fluted at intervals. Width is thereby maintained for a long period, and as each tooth body wears back the cutter is partly revolved to bring a fresh tooth into action.

Fig. 351 has the advantage of instantaneous release of the tail screws to withdraw tools for attention. The plates being pivoted on studs, and slotted out at the other end to drop over the shouldered stud, are consequently freed by upward swing.

Close Groupings.—The problem of attacking as many faces as possible simultaneously needs careful consideration of the lay-out of blocks, and if consecutive cutting takes place on some occasions clearances have to be arranged to reduce lost time as much as possible, in approaches and returns. This is the most noticeable on small automatic screw machines, where a second has to be considered. Balancing of cutting pressures is also sought, especially on the larger castings and forgings, and fragile subjects. Thin drums, rims, pulleys, liners, etc., are best tooled inside and out simultaneously. Should this not be practicable a steady may have to be employed to sustain the rim. Steadies are located against many other pieces whose length precludes machining without such support. Crankshafts and camshafts constitute the most familiar specimens. A hinged bearing containing split brasses is one mode of steadying, while Fig. 352 is a roller bracket suited for the proportions of the shaft.

Figs. 353 and 354 afford instances of the use of single, twin, and triple holders, while Fig. 355 is done by special main blocks, and one standard. The front block is controlled by a copying attachment to impart the directional movement shown by the arrow. In Fig. 356 (Fay) the front carriage also has copy

control to turn the outside diameter with roughing and finishing tools, then bore the recess. As the roughing tool is operating, the roughing facing tool on the back arm is also engaged, then the spindle speed is automatically increased and the finish turning and facing tools complete the surfaces. Finally the speed is reduced to the original rate, the recess is bored and radiused, and the outside radii finished from the back arm tools. On one type of manufacturing lathe roughing and finishing cuts are performed by tools moved by the saddle, the rear slide, and the overarm (Fig. 357). The tools in holders A, B, rough and finish-turn the top diameter, and rough and finish-form the recess in the front face. The tools in rear slide C rough the front face and groove, and are followed by finishers in overarm D.

On capstan and turret lathes the turning holder enables close grouping to be done by utilising as many as six bars in addition to the one for boring. The problem is to ensure rigidity with such a collection, and the overhead pilot-bar is the main agent in this respect. The boring-bar is also piloted whenever practicable (Fig. 358). Further stiffening is occasionally obtained by fastening a tie-link to connect the cutter-bars at positions as far as possible from the holder body. Roughing cuts are often made from the cross-slide before applying some of the turret tools, to ease their duty on the more difficult castings and forgings. Or the initial cuts are effected by the turret set, and cross-slide tools of ordinary or form type complete the outlines accurately.

Chucking.—Bound up with these problems of tool dispositions is that of suitable chucking methods, which generally have to be devised either to provide clearances for the blocks or tools, or are specially made up to give efficient grip or drive on perhaps narrow surfaces. Cutting behind shoulders or hubs is frequently done to avoid a rechucking, and here the drive or jaws may be appropriately designed to afford such facility.

REPAIRING GEAR TEETH

Replacing broken teeth in gear wheels should only be resorted to as a temporary measure of repair, or permanently in lightly loaded machinery, or where replacement of the whole is practically impossible. Replacing teeth in small wheels, such as are used in motor-car and motor-cycle gear-boxes, and which would need softening and re-hardening with special equipment, is unsatisfactory and would quickly prove unreliable. Generally, these wheels are designed on the strength of the steel, in order to keep weight and size small, and if the wheel is weakened by drilling or milling, the designed conditions of strength would not remain.

Temporary Repairs.—Temporary repairs to cast-iron, mild-steel, or brass wheels can be effected in several ways. If the

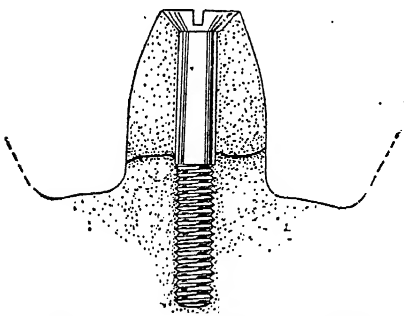


Fig 359.—A broken tooth held in place by means of a screw.

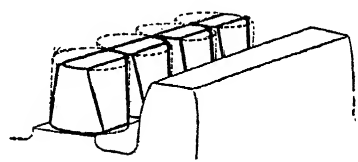


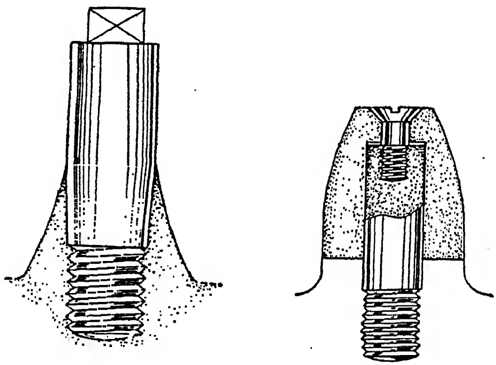
Fig. 360—A row of studs tapped into the wheel to take the place of a broken tooth.

tooth has broken clean and is recovered undamaged apart from the fracture, it can be fitted into position again and secured by two or three screws, passed down through the tooth and tapped into the wheel, as shown in Fig. 359. In order to secure perfect reseating of the fracture, the tooth should be drilled first with a small drill, and the tooth used as a guide for the drilling of the tapped holes in the wheel. The holes in both tooth and wheel can then be enlarged to their correct sizes.

If the tooth is broken in several pieces or is otherwise not usable, a row of studs can be tapped into the wheel, as shown in Fig. 360. The base of the tooth should be filed, or, if the wheel can be got to a machine, machined off, flat and level. The studs

should have a diameter equal to or more than the width of the tooth, to ensure, as far as is possible, a full tooth.

Small Studs.—Under-sized studs will cause jumping and may lead to other broken teeth, it being preferable to fit a smaller number of full-size studs than a larger number of narrower ones, if the width of the wheel leaves such a choice. The holes which have to be drilled and tapped for the fitting of the studs should be marked out accurately, so that the unthreaded portions of the studs fit close together. If possible, the end of the stud should bed down into solid material and a reasonable amount of the unthreaded portion of the stud enter into the wheel, as shown in



Figs. 361 *and* 362.—*How the studs should bed down into the wheel.* (*Right*) *How to make and fit a tooth.*

Fig. 361. The end of the stud should be filed off square or hexagonal to take a spanner, so that it can be forced home hard. Where the flange of the wheel is thin and will not stand a bedded-down stud, the hole should be tapped right through and a nut used on the under side, and provision made for locking it securely. The tapped holes should be on the tight side to reduce sloppiness or movement.

The studs may then be filed, or machined down to the shape of the other teeth, it being particularly necessary not to cut a " perfect " tooth but one which follows the " wear " line of the old teeth. A hardened-steel gauge can be made for this purpose from one of the other teeth.

A more satisfactory job can be made by making a tooth and securing it to the wheel as shown in Fig. 362. The studs which

carry all the strain must be a driving fit into the tooth, the screws in the top of the tooth merely holding the tooth down. This method ensures a perfect tooth surface, which is absent with the plain stud method.

A Perfect Repair.—Another method which can be used where the wheel can be put on the miller is shown in Fig. 363 and is as near a perfect repair as possible. A short screw can be tapped into the metal after the tooth has been driven home to prevent it sliding sideways.

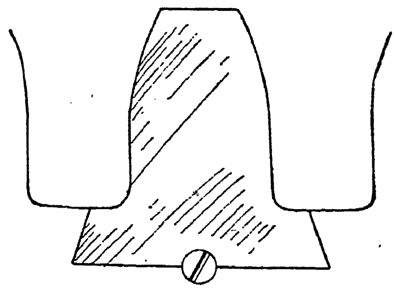


Fig. 363.—*The new tooth dovetailed in.*

This is the best method for repairing teeth in narrow wheels, where the width of the tooth will not allow of the fitting of studs, such as brass clock wheels. In these cases the tooth may be soldered into position.

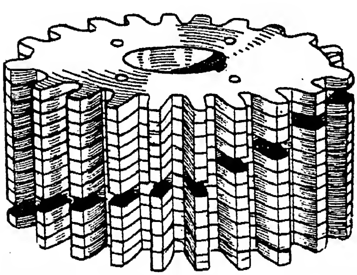
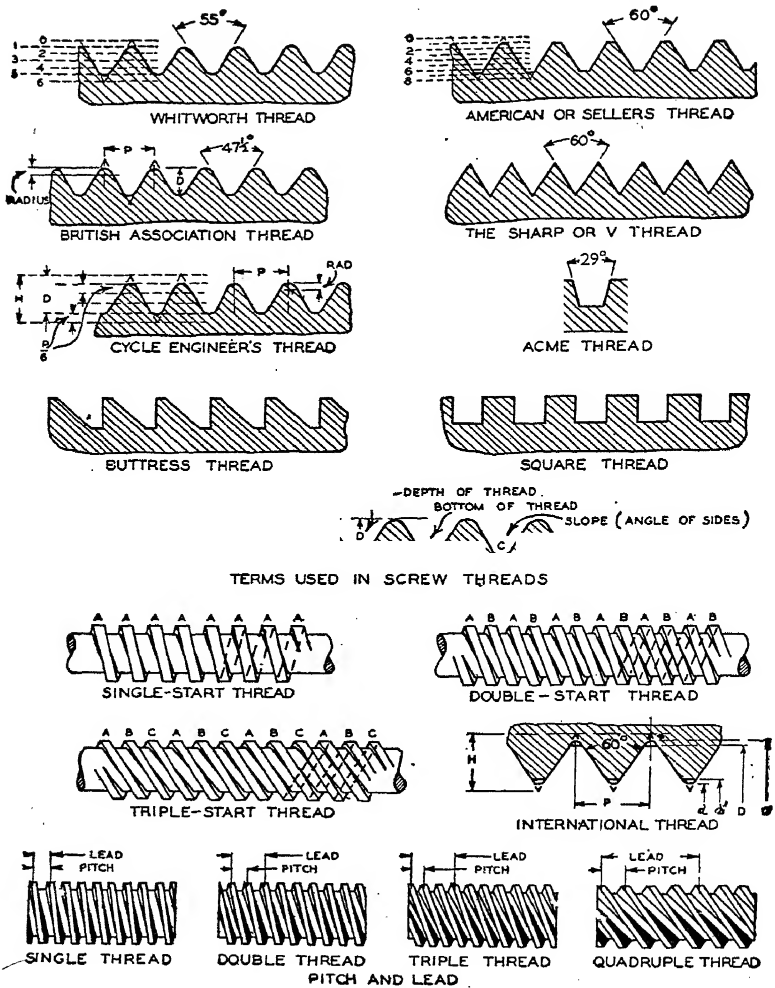


Fig. 364.—*How to repair a tooth in a fibre wheel.*

Fibre or hide wheels, which are made up from a number of disks bolted together, rarely suffer from one broken tooth, but such a condition may be caused by a piece of solid material dropping into them. A repair can be made by unshipping the pinion, knocking through the pins, and redistributing the disks, so that the faulty tooth appears all round the wheel, as shown in Fig. 364.

Repairing Small Gears.—Very small gears, such as mainspring barrels and others intended for light duty, may be repaired merely by drilling and tapping the root at the point where the tooth has broken off and inserting screwed pins, making sure that they are inserted at the correct pitch point.

All methods of cutting gears are dealt with in a companion work entitled " Gears and Gear Cutting."



Figs. 365–381.—*Screw threads.*

Change Wheels for Screw Cutting

Two alternative trains are given.

Threads per Inch to be Cut.	*Lead Screw, ¼-in. pitch.*				*Lead Screw, ½-in. pitch.*			
	Drivers.		*Driven.*		*Drivers.*		*Driven.*	
50	20	30	75	100	20	20	100	100
	20	40	80	125	20	30	120	125
48	20	25	60	100	20	25	100	120
	25	30	75	120	20	20	80	120
45	20	30	75	90	20	20	75	120
	20	40	90	100	20	25	90	125
40	20	55	100	110	20	30	100	120
	20	40	80	100	20	25	100	100
35	30	40	100	105	20	30	100	105
	20	40	70	100	25	30	105	125
30	20	60	90	100	20	40	100	120
	20	50	75	100	20	35	100	105
28	20	30	40	105	20	25	70	100
	20	30	60	70	20	45	105	120
26	20	30	60	65	20	25	65	100
	25	40	65	100	20	30	65	120
25	30	40	75	100	20	30	75	100
	20	60	75	100	20	60	120	125
24	20		120		25	30	75	120
	20	40	60	80	20	25	60	100
23	20		115		20	50	100	115
	30	40	60	115	20	30	60	115
22	20		110		20	30	60	110
	30	50	76	115	20	40	80	110
21	20	40	60	70	20	40	70	120
	30	40	70	90	20	30	70	90
20	20		100		20	40	80	100
	20	40	50	80	20	35	70	100
19	20		95		25	40	95	100
	30	40	60	95	20	60	95	120
18	20		90		25	40	75	120
	30	40	60	90	35	40	105	120
17	20		85		20	60	85	120
	30	40	60	85	20	45	85	90
16	20		80		25	30	50	120
	35	40	70	80	30	45	90	120
15	20		75		20	80	100	120
	20	40	30	100	20	70	100	105

Change Wheels for Screw Cutting—*continued*

Threads per Inch to be Cut.	*Lead-screw, ¼-in. pitch.*		*Lead Screw, ½-in. pitch.*	
	Drivers.	*Driven.*	*Drivers.*	*Driven.*
14	20	70	20 75	100 105
	30 40	60 70	20 50	70 100
13	20	65	20 50	65 100
	40 45	65 90	20 60	65 120
12	20	60	20	120
	30 50	60 75	25 60	90 100
11	40	110	20	110
	30 40	55 60	30 60	90 110
10	40	100	20	100
	30 40	50 60	35 60	100 105
9	40	90	20	90
	30 40	45 60	30 70	90 105
8	40	80	20	80
	20 75	50 60	35 60	70 120
7½	40	75	20	75
	20 80	50 60	30 80	75 120
7	40	70	20	70
	30 80	60 70	30 80	70 120
6½	40	65	20	65
	30 60	45 65	30 80	65 120
6	30	45	30	90
	20 60	40 45	35 80	70 120
5½	40	55	20	55
	40 60	30 110	40	110
5	40	50	30	75
	60	75	40	100
4½	40	45	40	90
	40 100	75 60	20	45
4	40	40	30	60
	30 105	90 35	40	80
3½	40	35	40	70
	40 60	30 70	30 90	45 105
3¼	80	65	40	65
	70 40	35 65	50 80	65 100
3	80	60	40	60
	40	30	30	45
2⅞	40 100	115 25	20 100	115 25
	40 120	115 30	40 100	115 50
2¾	80	55	40	55
	60 100	55 75	80	110

Change Wheels for Screw Cutting—*continued*

Threads per Inch to be Cut.	*Lead Screw, ¼-in. pitch.* Drivers.		Driven.		*Lead Screw, ½-in. pitch.* Drivers.		Driven.	
$2\frac{5}{8}$	40	100	105	25	80		105	
	40	120	105	30	40	100	105	50
$2\frac{1}{2}$	80		50		40		50	
	40	90	75	30	40	120	100	60
$2\frac{3}{8}$	40	100	95	25	80		95	
	40	120	95	30	40	100	95	50
$2\frac{1}{4}$	80		45		40		45	
	40	100	75	30	40	100	90	50
2	80		40		60		60	
	40	75	50	30	30	75	90	25
$1\frac{7}{8}$	40	80	50	30	80		75	
	40	80	75	20	40	80	100	30
$1\frac{3}{4}$	80		35		80		70	
	80	100	70	50	60	90	105	45
$1\frac{5}{8}$	60	80	65	30	60	100	75	65
	50	80	65	25	40	90	65	45
$1\frac{1}{2}$	80		30		80		60	
	60	100	75	30	60	110	90	55
$1\frac{3}{8}$	80	120	110	30	80		55	
	80	50	55	35	80	70	110	35
$1\frac{1}{4}$	80		25		80		50	
	80	120	75	40	40	120	100	30
$1\frac{1}{8}$	60	80	45	30	80		45	
	80	100	50	45	80	100	90	50
1	100		25		60		30	
	80	100	50	40	80		40	
One Thread in $1\frac{1}{4}$	100	120	60	40	100		40	
	75	50	30	25	80	75	60	40
One Thread in $1\frac{1}{2}$	80	90	40	30	90		30	
	70	75	35	25	60	70	40	35
One Thread in $1\frac{3}{4}$	70	75	30	25	75	105	90	25
	80	105	40	30	70	105	60	35
One Thread in 2	80	100	40	25	80	60	40	30
	75	80	30	25	70	110	55	35
One Thread in $2\frac{1}{4}$	75	90	30	25	90	105	60	35
	90	100	40	25	70	90	40	35
One Thread in $2\frac{1}{2}$	100	75	30	25	75	100	50	30
	100	120	40	30	75	110	55	30
One Thread in $2\frac{3}{4}$	100	110	40	25	100	110	50	40
	110	75	30	25	90	110	45	40

Change Wheels for Millimetre Pitches

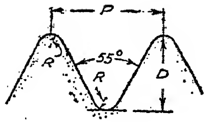
Pitch of Screw to be Cut.	*¼-in. Pitch Lead Screw.*		*½-in. Pitch Lead Screw.*	
Millimetres.	*Drivers.*	*Driven.*	*Drivers.*	*Driven.*
1 (·039 in.)	63 × 20	80 × 100	21 × 30	80 × 100
	35 × 45	100 × 100	21 × 45	100 × 120
2 (·079 in.)	63 × 30	60 × 100	63 × 20	80 × 100
	63 × 40	80 × 100	63 × 30	100 × 120
3 (·118 in.)	63 × 30	40 × 100	63 × 30	80 × 100
	63 × 45	60 × 100	63 × 45	100 × 120
4 (·157 in.)	63 × 30	50 × 60	63 × 30	60 × 100
	63 × 20	40 × 50	63 × 20	50 × 80
5 (·197 in.)	63 × 30	40 × 60	63 × 30	60 × 80
	45 × 70	50 × 80	45 × 70	80 × 100
6 (·236 in.)	63 × 45	50 × 60	63 × 30	50 × 80
	63 × 60	50 × 80	63 × 45	60 × 100
7 (·275 in.)	63 × 35	40 × 50	63 × 35	50 × 80
	63 × 70	50 × 80	63 × 70	80 × 100
8 (·315 in.)	63	50	63	100
	63 × 45	50 × 70	63 × 45	60 × 75
9 (·354 in.)	63 × 90	50 × 80	63 × 45	50 × 80
	63 × 45	40 × 50	63 × 90	80 × 100
10 (·393 in.)	63	40	63	80
	70 × 90	50 × 80	70 × 90	80 × 100
11 (·433 in.)	63 × 55	25 × 80	63 × 55	50 × 80
	63 × 110	50 × 80	63 × 110	80 × 100
12 (·474 in.)	63 × 30	20 × 50	63 × 30	40 × 50
	63 × 60	40 × 50	63 × 60	50 × 80
13 (·512 in.)	63 × 65	40 × 50	63 × 65	40 × 100
	63 × 65	25 × 80	63 × 65	50 × 80
14 (·551 in.)	63 × 70	40 × 50	63 × 70	50 × 80
	63 × 105	40 × 75	63 × 70	40 × 100
15 (·591 in.)	63 × 75	40 × 50	63 × 75	50 × 80
	63 × 90	40 × 60	63 × 90	60 × 80
16 (·630 in.)	63 × 80	40 × 50	63 × 80	50 × 80
	63 × 60	30 × 50	63 × 60	50 × 60
17 (·669 in.)	63 × 85	20 × 100	63 × 85	40 × 100
	63 × 85	40 × 50	63 × 85	50 × 80
18 (·708 in.)	63 × 90	40 × 50	63 × 90	50 × 80
	63 × 45	20 × 50	63 × 45	40 × 50
19 (·748 in.)	63 × 95	40 × 50	63 × 95	50 × 80
	63 × 95	20 × 100	63 × 95	40 × 100

Change Wheels for Millimetre Pitches—*continued*

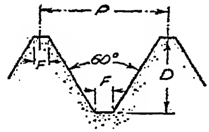
Pitch of Screw to be Cut.	*$\frac{1}{4}$-in. Pitch Lead Screw.*		*$\frac{1}{2}$-in. Pitch Lead Screw.*	
Millimetres.	*Drivers.*	*Driven.*	*Drivers.*	*Driven.*
20 (·787 in.)	63 × 75	25 × 60	63 × 75	50 × 60
	63 × 60	30 × 40	63 × 60	40 × 60
21 (·826 in.)	63 × 63	20 × 60	63 × 63	40 × 60
	63 × 63	30 × 40	63 × 63	30 × 80
22 (·866 in.)	63 × 55	20 × 50	63 × 55	40 × 50
	63 × 100	40 × 50	63 × 100	50 × 80
23 (·905 in.)	63 × 46	20 × 40	63 × 46	40 × 40
	63 × 115	40 × 50	63 × 115	50 × 80
24 (·945 in.)	63 × 90	30 × 50	63 × 90	50 × 60
	63 × 60	20 × 50	63 × 60	40 × 50
25 (·984 in.)	63 × 50	20 × 40	63 × 50	20 × 80
	70 × 90	40 × 40	70 × 90	40 × 80
26 (1·023 in.)	63 × 65	20 × 50	63 × 65	25 × 80
	63 × 65	25 × 40	63 × 65	40 × 50
27 (1·063 in.)	63 × 54	20 × 40	63 × 54	20 × 80
	63 × 81	30 × 40	63 × 81	40 × 60
28 (1·102 in.)	63 × 70	20 × 50	63 × 70	40 × 50
	63 × 70	25 × 40	63 × 70	25 × 80
29 (1·140 in.)	63 × 58	20 × 40	63 × 58	20 × 80
	63 × 145	20 × 100	63 × 145	40 × 100
30 (1·180 in.)	63 × 60	20 × 40	63 × 60	20 × 80
	63 × 90	30 × 40	63 × 90	40 × 60
31 (1·220 in.)	63 × 62	20 × 40	62 × 62	20 × 80
	63 × 62	25 × 32	63 × 62	40 × 40
32 (1·260 in.)	63 × 60	25 × 30	63 × 60	30 × 50
	63 × 80	25 × 40	63 × 80	40 × 50
33 (1·300 in.)	33 × 63	20 × 20	66 × 63	20 × 80
	66 × 63	20 × 40	63 × 99	40 × 60
34 (1·338 in.)	63 × 85	20 × 50	63 × 85	40 × 50
	63 × 85	25 × 40	63 × 85	25 × 80
35 (1·378 in.)	63 × 70	20 × 40	63 × 70	40 × 40
	63 × 105	30 × 40	63 × 70	20 × 80
36 (1·417 in.)	63 × 90	20 × 50	63 × 90	40 × 50
	63 × 90	25 × 40	63 × 90	25 × 80
37 (1·456 in.)	63 × 37	20 × 20	63 × 37	20 × 40
	63 × 74	20 × 40	63 × 74	20 × 80
38 (1·496 in.)	63 × 95	25 × 40	63 × 95	40 × 50
	63 × 95	20 × 50	63 × 95	20 × 100

Change Wheels for Millimetre Pitches—*continued*

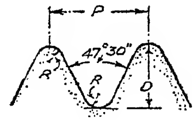
Pitch of Screw to be Cut.	*¼-in. Pitch Lead Screw.*		*½-in. Pitch Lead Screw.*	
Millimetres.	*Drivers.*	*Driven.*	*Drivers.*	*Driven.*
39 (1·535 in.)	63 × 78	20 × 40	63 × 78	40 × 40
	63 × 78	25 × 32	63 × 78	20 × 80
40 (1·575 in.)	63 × 80	20 × 40	63 × 80	40 × 40
	63 × 40	20 × 20	70 × 90	40 × 50
42 (1·653 in.)	63 × 84	20 × 40	63 × 105	40 × 50
	63 × 105	20 × 40	63 × 81	20 × 80
44 (1·732 in.)	63 × 55	20 × 25	63 × 55	20 × 50
	63 × 110	25 × 40	63 × 110	40 × 50
45 (1·770 in.)	63 × 45	20 × 20	63 × 45	20 × 40
	63 × 90	20 × 40	63 × 90	40 × 40
46 (1·811 in.)	63 × 115	20 × 50	63 × 115	40 × 50
	63 × 115	25 × 40	63 × 115	20 × 100
48 (1·890 in.)	63 × 60	20 × 25	63 × 60	25 × 40
	63 × 90	25 × 30	63 × 90	30 × 50
50 (1·968 in.)	63 × 50	20 × 20	63 × 50	20 × 40
	63 × 75	20 × 30	63 × 75	30 × 40
55 (2·165 in.)	63 × 55	20 × 20	63 × 55	20 × 40
	63 × 110	20 × 40	63 × 110	40 × 40
60 (2·362 in.)	63 × 60	20 × 20	63 × 60	20 × 40
	63 × 90	20 × 30	63 × 75	20 × 50
65 (2·560 in.)	63 × 65	20 × 20	63 × 65	20 × 40
	63 × 78	20 × 24	63 × 78	20 × 48
70 (2·756 in.)	63 × 70	20 × 20	63 × 70	20 × 40
	63 × 105	20 × 30	63 × 105	20 × 60
75 (2·953 in.)	63 × 75	20 × 20	63 × 75	20 × 40
	63 × 90	20 × 24	63 × 90	20 × 48
80 (3·149 in.)	63 × 80	20 × 20	63 × 80	20 × 40
	63 × 100	20 × 25	63 × 100	25 × 40
85 (3·346 in.)	63 × 85	20 × 20	63 × 85	20 × 40
	63 × 102	20 × 24	63 × 102	24 × 40
90 (3·543 in.)	63 × 90	20 × 20	63 × 90	20 × 40
	63 × 108	20 × 24	63 × 108	40 × 24
95 (3·740 in.)	63 × 95	20 × 20	63 × 95	20 × 40
	63 × 76	20 × 16	63 × 76	20 × 32
100 (3·930 in.)	63 × 100	20 × 20	63 × 100	20 × 40
	70 × 90	20 × 20	70 × 90	20 × 40



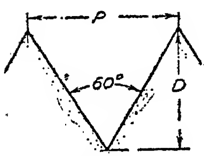
WHITWORTH
D = 0·6403 ÷ No of T.P.I"
R = 0·1373 ÷ No of T.P.I"



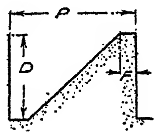
UNITED STATES ST'D.
D = 0·6495 ÷ No. of T.P.I"
F = 1 ÷ (8 X No. of T.P.I")



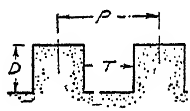
BRITISH ASSOCIATION
D = 0·6 P
R = 2P ÷ 11



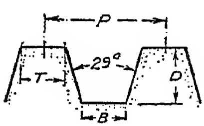
SHARP OR "V"



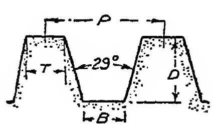
BUTTRESS
D = 3/4 P
F = 1/8 P



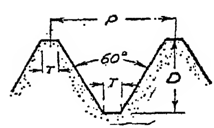
SQUARE
D = 1/2 P
T = 1/2 P



B = 0·3707P − 0·0052"
T = 0·3707 P



D = 0·6866 ÷ No of T.P.I"
B = 0·310P
T = 0·335 P



FRENCH & INTERNATIONAL
D = 0
T = 1-

Figs. 382 *to* 390.—*These diagrams indicate the thread forms and proportions of most of the standard screw threads.*

Whitworth Standard Threads

(With Equivalents in British Standard Fine)

$$p = \text{pitch} = \frac{1}{\text{No. threads per in.}} \qquad \begin{aligned} d &= \text{depth} = p \times \cdot 64033 \\ r &= \text{radius} = p \times \cdot 1373 \end{aligned}$$

Diameter. In.	*Threads per In.*		*Outside Diameter, In.*	*Pitch Diameter, In.*	*Root Diameter, In.*	*Tap Drill Size.*
	Whit-worth Std.	*Brit. Std. Fine.*				
$\frac{1}{16}$	60	—	0·0625	0·0518	0·0412	56
$\frac{3}{32}$	48	—	0·0938	0·0804	0·0671	49
$\frac{1}{8}$	40	—	0·1250	0·1090	0·0930	40
$\frac{5}{32}$	32	—	0·1563	0·1362	0·1162	31
$\frac{3}{16}$	24	—	0·1875	0·1608	0·1341	28
$\frac{7}{32}$	24	—	0·2188	0·1921	0·1654	18
$\frac{1}{4}$	20	—	0·2500	0·2180	0·1860	11
$\frac{1}{4}$	—	26	0·2500	0·2254	0·2001	7
$\frac{9}{32}$	—	26	0·2813	0·2566	0·2321	B
$\frac{5}{16}$	18	—	0·3125	0·2769	0·2414	D
$\frac{5}{16}$	—	22	0·3125	0·2834	0·2543	G
$\frac{3}{8}$	16	—	0·3750	0·3350	0·2950	N
$\frac{3}{8}$	—	20	0·3750	0·3430	0·3110	O
$\frac{7}{16}$	14	—	0·4375	0·3918	0·3460	S
$\frac{7}{16}$	—	18	0·4375	0·4019	0·3665	$\frac{3}{8}$
$\frac{1}{2}$	12	—	0·5000	0·4466	0·3933	X
$\frac{1}{2}$	—	16	0·5000	0·4600	0·4200	$\frac{7}{16}$
$\frac{9}{16}$	12	—	0·5625	0·5091	0·4558	$\frac{15}{32}$
$\frac{9}{16}$	—	16	0·5625	0·5225	0·4825	$\frac{1}{2}$
$\frac{5}{8}$	11	—	0·6250	0·5668	0·5086	$\frac{33}{64}$
$\frac{5}{8}$	—	14	0·6250	0·5793	0·5336	$\frac{35}{64}$
$\frac{11}{16}$	11	—	0·6875	0·6293	0·5711	$\frac{37}{64}$
$\frac{11}{16}$	—	14	0·6875	0·6418	0·5961	$\frac{39}{64}$
$\frac{3}{4}$	10	—	0·7500	0·6860	0·6219	$\frac{5}{8}$
$\frac{3}{4}$	—	12	0·7500	0·6966	0·6434	$\frac{21}{32}$
$\frac{13}{16}$	10	—	0·8125	0·7485	0·6844	$\frac{11}{16}$
$\frac{13}{16}$	—	12	0·8125	0·7591	0·7059	$\frac{23}{32}$
$\frac{7}{8}$	9	—	0·8750	0·8039	0·7327	$\frac{47}{64}$
$\frac{7}{8}$	—	11	0·8750	0·8168	0·7586	$\frac{49}{64}$
$\frac{15}{16}$	9	—	0·9375	0·8664	0·7952	$\frac{13}{16}$
1	8	—	1·0000	0·9200	0·8399	$\frac{27}{32}$
1	—	10	1·0000	0·9360	0·8720	$\frac{57}{64}$

Whitworth Standard Threads—*continued*

Diameter, In.	Threads per In. Whitworth Std.	Threads per In. Brit. Std. Fine.	Outside Diameter, In.	Pitch Diameter, In.	Root Diameter, In.	Tap Drill Size.
$1\frac{1}{8}$	7	—	1·1250	1·0335	0·9420	$\frac{61}{64}$
$1\frac{1}{8}$	—	9	1·1250	1·0539	0·9828	1
$1\frac{1}{4}$	7	—	1·2500	1·1585	1·0670	$1\frac{5}{64}$
$1\frac{1}{4}$	—	9	1·2500	1·1789	1·1078	$1\frac{1}{8}$
$1\frac{3}{8}$	6	—	1·3750	1·2683	1·1616	$1\frac{11}{64}$
$1\frac{3}{8}$	—	8	1·3750	1·2950	1·2150	$1\frac{15}{64}$
$1\frac{1}{2}$	6	—	1·5000	1·3933	1·2866	$1\frac{19}{64}$
$1\frac{1}{2}$	8	8	1·5000	1·4200	1·3400	$1\frac{23}{64}$
$1\frac{5}{8}$	5	—	1·6250	1·4969	1·3689	$1\frac{3}{8}$
$1\frac{3}{4}$	5	—	1·7500	1·6219	1·4939	$1\frac{1}{2}$
$1\frac{7}{8}$	$4\frac{1}{2}$	—	1·8750	1·7327	1·5904	$1\frac{19}{32}$
2	$4\frac{1}{2}$	—	2·0000	1·8577	1·7154	$1\frac{47}{64}$
$2\frac{1}{8}$	$4\frac{1}{2}$	—	2·1250	1·9827	1·8404	$1\frac{55}{64}$
$2\frac{1}{4}$	4	—	2·2500	2·0899	1·9298	$1\frac{15}{16}$
$2\frac{3}{8}$	4	—	2·3750	2·2149	2·0548	$2\frac{1}{16}$
$2\frac{1}{2}$	4	—	2·5000	2·3399	2·1798	$2\frac{3}{16}$
$2\frac{3}{4}$	$3\frac{1}{2}$	—	2·7500	2·5671	2·3841	$2\frac{25}{64}$
3	$3\frac{1}{2}$	—	3·0000	2·8171	2·6341	$2\frac{41}{64}$

Standard Brass Thread

Diameter, In.	Threads per In.	Depth of Thread, In.	Core Diam., In.	Tapping Size, In.
$\frac{1}{8}$	26	·0246	0·0758	No. 47
$\frac{1}{4}$	26	·0246	0·2008	,, 6
$\frac{3}{8}$	26	·0246	0·3258	Q
$\frac{1}{2}$	26	·0246	0·4508	$\frac{29}{64}$
$\frac{5}{8}$	26	·0246	0·5758	$\frac{37}{64}$
$\frac{3}{4}$	26	—	0·7008	$\frac{45}{64}$
$\frac{7}{8}$	26	·0246	0·8258	$\frac{53}{64}$
1	26	·0246	0·9508	$\frac{61}{64}$
$1\frac{1}{8}$	26	·0246	1·0758	$1\frac{5}{64}$
$1\frac{1}{4}$	26	·0246	1·2008	$1\frac{13}{64}$
$1\frac{1}{2}$	26	·0246	1·4508	$1\frac{29}{64}$

Whitworth Standard Pipe Threads

$$\text{Formula}\begin{cases} N = \text{number of threads per in.} \\ \text{Depth of thread} = \dfrac{\cdot 64}{N} \end{cases}$$

Pipe Diameters							
Pipe Size Nom. Inside.	*Approx Outside.*	*Threads per in.*	*Depth of Thread.*	*Gauge Diam.*	*Position of Gauge Diam.*	*Minimum Length of Thread*	*Drill Size.*
$\frac{1}{8}$		28	·0230	0·383			
$\frac{1}{4}$		19	·0335	0·518			
$\frac{3}{8}$		19	·0335	0·656			
		14	0455	0·825			
		14	·0455	0·902			
		14	·0455	1·041			
		14	·0455	1·189			
		11	·0580	1·309			
		11	·0580	1·650		1	
		11	·0580	1·882		1	
$1\frac{3}{4}$		11	·0580	2·116		$1\frac{1}{8}$	
2	$2\frac{3}{8}$	11	·0580	2·347			
	$2\frac{5}{8}$	11	·0580	2·587	$\frac{11}{16}$		
	3	11	·0580	2·960	$\frac{11}{16}$		
$2\frac{3}{4}$	$3\frac{1}{4}$	11	·0580	3·210		$1\frac{3}{8}$	
3	$3\frac{1}{2}$	11	·0580	3·460		$1\frac{3}{8}$	
$3\frac{1}{4}$	$3\frac{3}{4}$	11	·0580	3·700		$1\frac{1}{2}$	
$3\frac{1}{2}$	4	11	·0580	3·950		$1\frac{1}{2}$	
$3\frac{3}{4}$	$4\frac{1}{4}$	11	·0580	4·200			
4	$4\frac{1}{2}$	11	·0580	4·450			
$4\frac{1}{2}$	5	11	·0580	4·950			
5	$5\frac{1}{2}$	11	·0580	5·450			
$5\frac{1}{2}$	6	11	·0580	5·950			
6	$6\frac{1}{2}$	11	·0580	6·450	$1\frac{3}{8}$		

For Basic Sizes and Tolerances of Pipe Threads, see B.S. No. 21, 1938.

Whitworth Standard Hexagon Nuts and Bolts

Diam.	Hexagonal Nuts. Across Flats.	Hexagonal Nuts. Across Corners.	Thickness of Bolt Heads.	Diam.	Hexagonal Nuts. Across Flats.	Hexagonal Nuts. Across Corners.	Thickness of Bolt Heads.
In.				In.			
$\frac{1}{8}$	0·338	0·390	0·1093	$2\frac{3}{4}$	4·18	4·82	2·4062
$\frac{3}{16}$	0·448	0·517	0·164	$2\frac{7}{8}$	4·34	5·02	2·5156
$\frac{1}{4}$	0·525	0·606	0·2187	3	4·53	5·23	2·625
$\frac{5}{16}$	0·601	0·694	0·2734	$3\frac{1}{8}$	4·69	5·41	2·7343
$\frac{3}{8}$	0·709	0·819	0·3281	$3\frac{1}{4}$	4·85	5·6	2·8256
$\frac{7}{16}$	0·820	0·947	0·3828	$3\frac{3}{8}$	5·01	5·78	2·9531
$\frac{1}{2}$	0·920	1·06	0·4375	$3\frac{1}{2}$	5·17	5·98	3·0624
$\frac{9}{16}$	1·01	1·16	0·4921	$3\frac{5}{8}$	5·36	6·19	3·1718
$\frac{5}{8}$	1·1	1·27	0·5468	$3\frac{3}{4}$	5·55	6·41	3·2812
$\frac{11}{16}$	1·2	1·38	0·6016	$3\frac{7}{8}$	5·75	6·64	3·3906
$\frac{3}{4}$	1·3	1·5	0·6562	4	5·95	6·87	3·5
$\frac{13}{16}$	1·39	1·6	0·7064	$4\frac{1}{8}$	6·16	7·11	3·6094
$\frac{7}{8}$	1·48	1·7	0·7656	$4\frac{1}{4}$	6·37	7·36	3·7046
$\frac{15}{16}$	1·57	1·82	0·8203	$4\frac{3}{8}$	6·60	7·62	3·8271
1	1·67	1·93	0·875	$4\frac{1}{2}$	6·82	7·88	3·9374
$1\frac{1}{8}$	1·86	2·15	0·9843	$4\frac{5}{8}$	7·06	8·15	4·0469
$1\frac{1}{4}$	2·05	2·36	1·0937	$4\frac{3}{4}$	7·30	8·43	4·1562
$1\frac{3}{8}$	2·21	2·55	1·2031	$4\frac{7}{8}$	7·55	8·72	4·2656
$1\frac{1}{2}$	2·41	2·78	1·3125	5	7·80	9·01	4·375
$1\frac{5}{8}$	2·57	2·97	1·4128	$5\frac{1}{8}$	8·06	9·31	4·4844
$1\frac{3}{4}$	2·75	3·18	1·5312	$5\frac{1}{4}$	8·35	9·64	4·5926
$1\frac{7}{8}$	3·02	3·48	1·6406	$5\frac{3}{8}$	8·60	9·93	4·7031
2	3·15	3·63	1·75	$5\frac{1}{2}$	8·85	10·22	4·8124
$2\frac{1}{8}$	3·34	3·85	1·8523	$5\frac{5}{8}$	9·15	10·57	4·9218
$2\frac{1}{4}$	3·54	4·09	1·9687	$5\frac{3}{4}$	9·45	10·91	5·0312
$2\frac{3}{8}$	3·75	4·33	2·0781	$5\frac{7}{8}$	9·75	11·26	5·1406
$2\frac{1}{2}$	3·89	4·49	2·1875	6	10·00	11·55	5·25
$2\frac{5}{8}$	4·05	4·67	2·2968				

For details of Setscrews, Split-pins, Washers, and Studs, see B.S. 190, 1924.

International and French Standard Thread Gauges

(Metric System)

$$\begin{cases} p = \text{pitch} \\ d = \text{depth} = p \\ f = \text{flat} \quad = \dfrac{p}{8} \end{cases}$$

Diameter of Screw, mm.	*Pitch, mm.*	*Diameter at Root of Thread, mm.*	*Width of Flat, mm.*
3	0·5	2·35	·06
4	0·75	3·03	·09
5	0·75	4·03	·09
6	1·0	4·70	·13
7	1·0	5·70	·13
8	1·0	6·70	·13
8	1·25	6·38	·16
9	1·0	7·70	·13
9	1·25	7·38	·16
10	1·5	8·05	·19
11	1·5	9·05	·19
12	1·5	9·73	·19
12	1·75	10·05	·22
14	2·0	11·40	·25
16	2·0	13·40	·25
18	2·5	14·75	·31
20	2·5	16·75	·31
22	2·5	18·75	·31
24	3·0	20·10	·38
26	3·0	22·10	·38
27	3·0	23·10	·38
28	3·0	24·10	·38
30	3·5	25·45	·44
32	3·5	27·45	·44
33	3·5	28·45	·44
34	3·5	29·45	·44
36	4·0	30·80	5
38	4·0	32·80	·5
39	4·0	33·80	·5
40	4·0	34·80	·5
42	4·5	36·15	·56
44	4·5	38·15	·56

International and French Standard Thread Gauges—*contd.*

Diameter of Screw, mm.	*Pitch, mm.*	*Diameter at Root of Thread, mm.*	*Width of Flat, mm.*
45	4·5	39·15	·56
46	4·5	40·15	·56
48	5·0	41·51	·63
50	5·0	43·51	·63
52	5·0	45·51	·63
56	5·5	48·86	·69
60	5·5	52·86	·69

British Standard Fine

Diameter.	*Threads per In.*	*Pitch, In.*	*Depth of Thread.*	*Core Diam., In.*	*Diam. of Tap Drill, In.*
$\frac{1}{4}$	26	·0385	·0246	0·2007	No. 5
$\frac{5}{16}$	22	·0455	·0291	0·2543	G
$\frac{3}{8}$	20	·0500	·0320	0·3110	O
$\frac{7}{16}$	18	·0556	·0356	0·3664	U
$\frac{1}{2}$	16	·0625	·0400	0·4200	$\frac{27}{64}$
$\frac{9}{16}$	16	·0625	·0400	0·4825	$\frac{31}{64}$
$\frac{5}{8}$	14	·0714	·0457	0·5335	$\frac{35}{64}$
$\frac{11}{16}$	14	·0714	·0457	0·5960	$\frac{19}{32}$
$\frac{3}{4}$	12	·0833	·0534	0·6433	$\frac{21}{32}$
$\frac{13}{16}$	12	·0833	·0534	0·7058	18 mm.
$\frac{7}{8}$	11	·0909	·0582	0·7586	$\frac{49}{64}$
$\frac{15}{16}$	11	·0909	·0582	0·8211	21 mm.
1	10	·1000	·0640	0·8719	$\frac{7}{8}$
$1\frac{1}{8}$	9	·1111	·0711	0·9827	$\frac{63}{64}$
$1\frac{1}{4}$	9	·1111	·0711	1·1077	$1\frac{7}{64}$
$1\frac{3}{8}$	8	·125	·0800	1·2149	$1\frac{7}{32}$
$1\frac{1}{2}$	8	·125	·0800	1·3399	$1\frac{11}{32}$
$1\frac{5}{8}$	8	·125	·0800	1·4649	$1\frac{15}{32}$
$1\frac{3}{4}$	7	·1429	·0915	1·5670	40 mm.
$1\frac{7}{8}$	7	·1429	·0915	1·6920	$1\frac{45}{64}$
2	7	·1429	·0915	1·8170	$1\frac{53}{64}$
$2\frac{1}{8}$	7	·1429	·0915	1·9420	$1\frac{61}{64}$
$2\frac{1}{4}$	6	·1667	·1067	2·0366	52 mm.
$2\frac{3}{8}$	6	·1667	·1067	2·1616	55 mm.
$2\frac{1}{2}$	6	·1667	·1067	2·2866	$2\frac{5}{16}$

A.S.M.E. Standard Threads

(Formula same as U.S. Standard)

$$p = \text{pitch} = \frac{1}{\text{No. threads per in.}} \qquad d = \text{depth} = p \times \cdot 64952 \qquad f = \text{flat} = \frac{p}{8}$$

Nominal Size.	*Outside Diameter, In.*	*Pitch Diameter, In.*	*Root Diameter, In.*	*Tap Drill Size.*
0–80	·0600	·0519	·0438	56
1–56	·0730	·0614	·0498	55
64	·0730	·0629	·0527	54
72	·0730	·0640	·0550	53
2–56	·0860	·0744	·0628	51
64	·0860	·0759	·0657	50
3–48	·0990	·0855	·0719	48
56	·0990	·0874	·0758	47
4–32	·1120	·0917	·0714	48
36	·1120	·0940	·0759	46
40	·1120	·0958	·0795	45
48	·1120	·0985	·0849	43
5–36	·1250	·1078	·0889	42
40	·1250	·1088	·0925	40
44	·1250	·1102	·0955	39
6–32	·1380	·1777	·0974	38
36	·1380	·1200	·1019	36
40	·1380	·1218	·1055	35
7–30	·1510	·1294	·1077	33
32	·1510	·1307	·1104	32
36	·1510	·1330	·1149	31
8–30	·1640	·1423	·1207	30
32	·1640	·1437	·1234	30
36	·1640	·1460	·1279	29
40	·1640	·1478	·1315	29
9–24	·1770	·1499	·1229	30
30	·1770	·1553	·1337	29
32	·1770	·1567	·1364	28
10–24	·1900	·1629	·1359	28
28	·1900	·1668	·1436	26

A.S.M.E. Standard Threads—*continued*

Nominal Size.	*Outside Diameter, In.*	*Pitch Diameter, In.*	*Root Diameter, In.*	*Tap Drill Size.*
30	·1900	·1684	·1467	24
32	·1900	·1697	·1494	23
12–24	·2160	·1889	·1619	19
28	·2160	·1928	·1696	17
32	·2160	·1957	·1754	16
14–20	·2420	·2095	·1770	14
24	·2420	·2149	·1879	10
16–18	·2680	·2319	·1966	8
20	·2680	·2355	·2030	4
22	·2680	·2385	·2090	3
18–18	·2940	·2579	·2218	1
20	·2940	·2615	·2290	A
20–16	·3200	·2794	·2388	C
18	·3200	·2839	·2478	F
20	·3200	·2875	·2550	G
22–16	·3460	·3054	·2648	T
18	·3460	·3099	·2738	R
24–16	·3720	·3314	·2908	M
18	·3720	·3359	·2998	N
26–14	·3980	·3516	·3052	O
16	·3980	·3574	·3168	P
28–14	·4240	·3776	·3312	R
16	·4240	·3834	·3428	S
30–14	·4500	·4036	·3572	U
16	·4500	·4094	·3688	V

Model Screw Threads

$\frac{1}{4}$ in. and less . .	40 threads per inch
$\frac{5}{16}$ in. . . .	32 threads per inch
$\frac{3}{8}$ in.	32 threads per inch
$\frac{7}{16}$ in. . . .	26 threads per inch
$\frac{1}{2}$ in.	26 threads per inch

United States Standard Form Thread

Including S.A.E. Standard

$$\text{Formula}\quad \begin{aligned} p &= \text{pitch} = \frac{1}{\text{No. threads per in.}} \\ d &= \text{depth} = p \times \cdot 64952 \\ f &= \text{flat} = \frac{p}{8} \end{aligned}$$

Diam., In.	Threads per In.			Outside Diameter, In.	Pitch Diameter, In.	Root Diameter, In.	Tap Drill Size.
	U.S. Std.	S.A.E. Std.	U.S. Form.				
$\frac{1}{16}$	—	—	60	·0625	·0517	·0409	57
$\frac{1}{16}$	64	—	—	·0625	·0524	·0422	56
$\frac{1}{16}$	—	—	72	·0625	·0535	·0445	55
$\frac{5}{64}$	—	—	56	·0781	·0665	·0549	53
$\frac{5}{64}$	60	—	—	·0781	·0673	·0565	53
$\frac{3}{32}$	—	—	48	·0938	·0803	·0667	50
$\frac{3}{32}$	50	—	—	·0938	·0808	·0678	50
$\frac{3}{32}$	—	—	56	·0938	·0821	·0706	49
$\frac{3}{32}$	—	—	60	·0938	·0829	·0721	48
$\frac{7}{64}$	48	—	—	·1094	·0959	·0823	44
$\frac{1}{8}$	—	—	32	·1250	·1047	·0844	43
$\frac{1}{8}$	—	—	36	·1250	·1070	·0889	42
$\frac{1}{8}$	40	—	—	·1250	·1088	·0925	41
$\frac{1}{8}$	—	—	48	·1250	·1115	·0979	39
$\frac{9}{64}$	—	—	32	·1406	·1203	·1000	37
$\frac{9}{64}$	—	—	36	·1406	·1226	·1045	35
$\frac{9}{64}$	40	—	—	·1406	·1244	·1081	34
$\frac{5}{32}$	—	—	32	·1563	·1360	·1157	31
$\frac{5}{32}$	36	—	—	·1563	·1382	·1202	$\frac{1}{8}$
$\frac{5}{32}$	—	—	40	·1563	·1400	·1238	30
$\frac{11}{64}$	32	—	—	·1719	·1505	·1313	29
$\frac{11}{64}$	—	—	36	·1719	·1538	·1358	28
$\frac{3}{16}$	24	—	—	·1875	·1604	·1334	29
$\frac{3}{16}$	—	—	30	·1875	·1658	·1442	26
$\frac{3}{16}$	—	—	32	·1875	·1672	·1469	25
$\frac{3}{16}$	—	—	36	·1875	·1695	·1514	23
$\frac{13}{64}$	24	—	—	·2031	·1760	·1490	24

United States Standard Form Thread—*continued*
Including S.A.E. Standard

Diam., In.	*Threads per In.*			*Outside Diameter, In.*	*Pitch Diameter, In.*	*Root Diameter, In.*	*Tap Drill Size.*
	U.S. Std.	*S.A.E. Std.*	*U.S. Form.*				
$\frac{13}{64}$	—	—	32	·2031	·1828	·1625	19
$\frac{7}{32}$	24	—	—	·2188	·1916	·1646	19
$\frac{7}{32}$	—	—	28	·2188	·1956	·1724	16
$\frac{7}{32}$	—	—	32	·2188	·1985	·1782	14
$\frac{15}{64}$	24	—	—	·2344	·2073	·1806	13
$\frac{15}{64}$	—	—	28	·2344	·2112	·1880	10
$\frac{15}{64}$	—	—	32	·2344	·2141	·1942	8
$\frac{1}{4}$	20	—	—	·2500	·2176	·1850	12
$\frac{1}{4}$	—	—	24	·2500	·2229	·1959	7
$\frac{1}{4}$	—	28	—	·2500	·2268	·2306	4
$\frac{1}{4}$	—	—	32	·2500	·2297	·2094	3
$\frac{5}{16}$	18	—	—	·3125	·2764	·2403	D
$\frac{5}{16}$	—	—	20	·3125	·2800	·2476	E
$\frac{5}{16}$	—	24	—	·3125	·2854	·2584	G
$\frac{5}{16}$	—	—	32	·3125	·2922	·2719	J
$\frac{3}{8}$	16	—	—	·3750	·3344	·2938	N
$\frac{3}{8}$	—	—	18	·3750	·3389	·3029	$\frac{5}{16}$
$\frac{3}{8}$	—	—	20	·3750	·3425	·3100	P
$\frac{3}{8}$	—	24	—	·3750	·3479	·3209	Q
$\frac{7}{16}$	14	—	—	·4375	·3911	·3447	S
$\frac{7}{16}$	—	20	—	·4375	·4050	·3726	V
$\frac{7}{16}$	—	—	24	·4375	·4104	·3834	X
$\frac{1}{2}$	—	—	12	·5000	·4459	·3918	Y
$\frac{1}{2}$	13	—	—	·5000	·4501	·4001	$\frac{13}{32}$
$\frac{1}{2}$	—	20	—	·5000	·4675	·4351	$\frac{29}{64}$
$\frac{1}{2}$	—	—	24	·5000	·4729	·4459	$\frac{29}{64}$
$\frac{9}{16}$	12	—	—	·5625	·5084	·4542	$\frac{15}{32}$
$\frac{9}{16}$	—	18	—	·5625	·5264	·4903	$\frac{1}{2}$
$\frac{5}{8}$	11	—	—	·6250	·5660	·5069	$\frac{33}{64}$
$\frac{5}{8}$	—	—	12	·6250	·5709	·5168	$\frac{17}{32}$
$\frac{5}{8}$	—	18	—	·6250	·5889	·5528	$\frac{9}{16}$
$\frac{11}{16}$	11	—	—	·6875	·6285	·5694	$\frac{37}{64}$
$\frac{11}{16}$	—	—	12	·6875	·6334	·5793	$\frac{19}{32}$
$\frac{11}{16}$	—	16	—	·6875	·6469	·6063	$\frac{39}{64}$
$\frac{3}{4}$	10	—	—	·7500	·6851	·6201	$\frac{5}{8}$
$\frac{3}{4}$	—	—	12	·7500	·6959	·6418	$\frac{21}{32}$
$\frac{3}{4}$	—	16	—	·7500	·7094	·6688	$\frac{43}{64}$

British Association Screws

This is adopted as the Standard Gauge by the Post Office Telegraphs Department and most large electrical firms, and approved by the Engineering Standards Committee.

No.	*Absolute Dimensions in Millimetres.*		*Approximate Number of Threads per Inch.*	*Approximate Dimensions in Inches.*	
	Full Diameter.	*Pitch.*		*Full Diameter.*	*Pitch.*
25	0·25	0·07	362·8	·010	·0028
24	0·29	0·08	317·5	·011	·0031
23	0·33	0·09	282·2	·013	·0035
22	0·37	0·10	254·0	·015	·0039
21	0·42	0·11	230·9	·017	·0043
20	0·48	0·12	211·6	·019	·0047
19	0·54	0·14	181·4	·021	·0055
18	0·62	0·15	169·3	·024	·0059
17	0·70	0·17	149·4	·028	·0067
16	0·79	0·19	133·7	·031	·0075
15	0·90	0·21	121·0	·035	·0083
14	1·0	0·23	110·4	·039	·0091
13	1·2	0·25	101·6	·047	·0098
12	1·3	0·28	90·7	·051	·0110
11	1·5	0·31	81·9	·059	·0122
10	1·7	0·35	72·6	·067	·0138
9	1·9	0·39	65·1	·075	·0154
8	2·2	0·43	59·1	·087	·0169
7	2·5	0·48	52·9	·098	·0189
6	2·8	0·53	47·9	·110	·0209
5	3·2	0·59	43·0	·126	·0232
4	3·6	0·66	38·5	·142	·0260
3	4·1	0·73	34·8	·161	·0287
2	4·7	0·81	31·4	·185	·0319
1	5·3	0·90	28·2	·209	·0354
0	6·0	1·00	25·4	·236	·0394

Acme Standard Screw Thread

$$\text{Width of point of tool for screw or tap thread} = \frac{\cdot 3707}{\text{threads per in.}} - \cdot 0052$$

$$\text{Formula}\begin{cases} p = \text{pitch} = \dfrac{1}{\text{No. threads per inch}} \\ d = \text{depth} = \frac{1}{2}p + \cdot 010 \\ f = \text{flat on top of thread} = p \times \cdot 3707 \\ f' = \text{“ on bottom ”} = p \times \cdot 3707 - \cdot 0052 \end{cases}$$

Pitch.	*No. of Threads per In.*	*Depth of Thread.*	*Width at Top of Thread.*	*Width at Bottom of Thread.*	*Space at Top of Thread.*	*Thickness at Root of Thread*
2	$\frac{1}{2}$	1·010	·7414	·7362	1·2586	1·2637
$1\frac{7}{8}$	$\frac{8}{15}$	0·9475	·6950	·6897	1·1799	1·1850
$1\frac{3}{4}$	$\frac{4}{7}$	0·8850	·6487	·6435	1·1012	1·1064
$1\frac{5}{8}$	$\frac{8}{13}$	0·8225	·6025	·5973	1·0226	1·0277
$1\frac{1}{2}$	$\frac{2}{3}$	0·7600	·5560	·5508	0·9439	0·9491
$1\frac{7}{16}$	$\frac{16}{23}$	0·7287	·5329	·5277	0·9046	0·9097
$1\frac{3}{8}$	$\frac{8}{11}$	0·6975	·5097	·5045	0·8652	0·8704
$1\frac{5}{16}$	$\frac{16}{21}$	0·6662	·4865	·4813	0·8259	0·8311
$1\frac{1}{4}$	$\frac{4}{5}$	0·635	·4633	·4581	0·7866	0·7918
$1\frac{3}{16}$	$\frac{16}{19}$	0·6037	·4402	·4350	0·7472	0·7525
$1\frac{1}{8}$	$\frac{8}{9}$	0·5725	·4170	·4118	0·7079	0·7131
$1\frac{1}{16}$	$\frac{16}{17}$	0·5412	·3938	·3886	0·6686	0·6739
1	1	0·510	·3707	·3655	0·6293	0·6345
$\frac{15}{16}$	$1\frac{1}{15}$	0·4787	·3476	·3424	0·5898	0·5950
$\frac{7}{8}$	$1\frac{1}{7}$	0·4475	·3243	·3191	0·5506	0·5558
$\frac{13}{16}$	$1\frac{3}{13}$	0·4162	·3012	·2960	0·5112	0·5164
$\frac{3}{4}$	$1\frac{1}{3}$	0·385	·2780	·2728	0·4720	0·4772
$\frac{11}{16}$	$1\frac{5}{11}$	0·3537	·2548	·2496	0·4327	0·4379
$\frac{2}{3}$	$1\frac{1}{2}$	0·3433	·2471	·2419	0·4194	0·4246
$\frac{5}{8}$	$1\frac{3}{5}$	0·3225	·2316	·2264	0·3934	0·3986
$\frac{9}{16}$	$1\frac{7}{9}$	0·2912	·2085	·2033	0·3539	0·3591
$\frac{1}{2}$	2	0·260	·1853	·1801	0·3147	0·3199
$\frac{7}{16}$	$2\frac{2}{7}$	0·2287	·1622	·1570	0·2752	0·2804
$\frac{2}{5}$	$2\frac{1}{2}$	0·210	·1482	·1430	0·2518	0·2570
$\frac{3}{8}$	$2\frac{2}{3}$	0·1975	·1390	·1338	0·2359	0·2411
$\frac{1}{3}$	3	0·1766	·1235	·1183	0·2098	0·2150
$\frac{5}{16}$	$3\frac{1}{5}$	0·1662	·1158	·1106	0·1966	0·2018

Acme Standard Screw Thread—*continued*

Pitch.	*No. of Threads per In.*	*Depth of Thread*	*Width at Top of Thread.*	*Width at Bottom of Thread.*	*Space at Top of Thread.*	*Thickness at Root of Thread.*
$\frac{2}{7}$	$3\frac{1}{2}$	0·1528	·1059	·1007	0·1797	0·1849
$\frac{1}{4}$	4	0·1350	·0927	·0875	0·1573	0·1625
$\frac{2}{9}$	$4\frac{1}{2}$	0·1211	·0824	·0772	0·1398	0·1450
$\frac{1}{5}$	5	0·110	·0741	·0689	0·1259	0·1311
$\frac{3}{16}$	$5\frac{1}{3}$	0·1037	·0695	·0643	0·1179	0·1232
$\frac{1}{6}$	6	0·0933	·0617	·0565	0·1049	0·1101
$\frac{1}{7}$	7	0·0814	·0530	·0478	0·0899	0·0951
$\frac{1}{8}$	8	0·0725	·0463	·0411	0·0787	0·0839
$\frac{1}{9}$	9	0·0655	·0413	·0361	0·0699	0·0751
$\frac{1}{10}$	10	0·060	·0371	·0319	0·0629	0·0681
$\frac{1}{16}$	16	0·0412	·0232	·0180	0·0392	0·0444

Metric Screw Threads

French and International Standard

(*Large Sizes*)

Outside Diameter, mm.	Pitch, mm. French.	Pitch, mm. International.	Pitch Diameter, mm.	Root Diameter, mm.	Tap Drill, mm.
18	2·5	2·5	16·38	14·75	15·0
20	2·5	2·5	18·38	16·75	17·0
22	2·5	2·5	20·38	18·75	19·0
24	3·0	3·0	22·05	20·10	20·5
26	3·0	—	24·05	22·10	22·5
27	—	3·0	25·05	23·10	23·5
28	3·0	—	26·05	24·10	24·5
30	3·5	3·5	27·73	25·45	25·5
32	3·5	—	29·73	27·45	27·5
33	—	3·5	30·73	28·45	28·5
34	3·5	—	31·73	29·45	29·5
36	4·0	4·0	33·40	30·80	31·0
38	4·0	—	35·40	32·80	33·0
39	—	4·0	36·40	33·80	34·0
40	4·0	—	37·40	34·80	35·0
42	4·5	4·5	39·08	36·15	36·5
44	4·5	—	41·08	38·15	38·5
45	—	4·5	42·08	39·15	39·5
46	4·5	—	43·08	40·15	40·5
48	5·0	5·0	44·75	41·50	42·0
50	5·0	—	46·75	43·50	44·0
52	—	5·0	48·75	45·50	46·0
56	—	5·5	52·43	48·85	49·0
60	—	5·5	56·43	52·85	53·0
64	—	6·0	60·10	56·20	56·5
68	—	6·0	64·10	60·20	60·5
72	—	6·5	67·78	63·56	64·0
76	—	6·5	71·78	67·56	68·0
80	—	7·0	75·45	70·91	71·0

Circular Pitch

(See companion work, *Gears and Gear Cutting*.)

Circular Pitch is the Distance from the Centre of one Tooth to the Centre of the next Tooth, measured along the Pitch Circle.

To Get	*Having*	*Rule.*	*Formula.*
The Circular Pitch	The Diametral Pitch	Divide 3·1416 by the Diametral Pitch	$P' = \frac{3{\cdot}1416}{P}$
The Circular Pitch	The Pitch Diameter and Number of Teeth	Divide Pitch Diameter by the product of 0·3183 and Number of Teeth	$P' = \frac{D'}{0{\cdot}3183N}$
The Circular Pitch	The Outside Diameter and Number of Teeth	Divide Outside Diameter by the product of 0·3183 and Number of Teeth plus 2	$P' = \frac{D}{0{\cdot}3183(N+2)}$
Pitch Diameter	Number of Teeth and the Circular Pitch	The continued product of the Number of Teeth, the Circular Pitch and 0·3183	$D' = NP'{\cdot}3183$
Pitch Diameter	The Number of Teeth and the Outside Diameter	Divide the product of Number of Teeth and Outside Diameter by Number of Teeth plus 2	$D' = \frac{ND}{N+2}$
Pitch Diameter	The Outside Diameter and Circular Pitch	Subtract from the Outside Diameter the product of the Circular Pitch and 0·6366	$D' = D - (P'{\cdot}6366)$
Pitch Diameter	Addendum and the Number of Teeth	Multiply the Number of Teeth by the Addendum	$D' = Ns$

Outside Diameter	Number of Teeth and the Circular Pitch	The continued product of the number of Teeth plus 2, the Circular Pitch and 0·3183	$D = (N + 2)P'.3183$
Outside Diameter	The Pitch Diameter and Circular Pitch	Add to the Pitch Diameter the product of the Circular Pitch and 0·6366	$D = D' + (P'.6366)$
Outside Diameter	The Number of Teeth and the Addendum	Multiply Addendum by Number of Teeth plus 2	$D = s(N + 2)$
Number of Teeth	The Pitch Diameter and Circular Pitch	Divide the product of Pitch Diameter and 3·1416 by the Circular Pitch	$N = \frac{D'3.1416}{P'}$
Thickness of Tooth	The Circular Pitch	One half the Circular Pitch	$t = \frac{P'}{2}$
Addendum	The Circular Pitch	Multiply the Circular Pitch by 0·3183 or $s = \frac{D'}{N}$	$s = P'.3183$
Dedendum	The Circular Pitch	Multiply the Circular Pitch by 0·3683	$s + f = P'.3683$
Working Depth	The Circular Pitch	Multiply the Circular Pitch by 0·6366	$D'' = P'.6366$
Whole Depth	The Circular Pitch	Multiply the Circular Pitch by 0·6866	$D'' + f = P'.6866$
Clearance	The Circular Pitch	Multiply the Circular Pitch by 0·05	$f = P'.05$
Clearance	Thickness of Tooth	One-tenth the Thickness of Tooth at Pitch Line	$f = \frac{t}{10}$

Diametral Pitch

(See companion work, *Gears and Gear Cutting*.)

Diametral Pitch is the Number of Teeth to each Inch of the Pitch Diameter.

To Get	*Having*	*Rule.*	*Formula.*
The Diametral Pitch	The Circular Pitch	Divide 3·1416 by the Circular Pitch	$P = \frac{3{\cdot}1416}{P'}$
The Diametral Pitch	The Pitch Diameter and Number of Teeth	Divide Number of Teeth by Pitch Diameter	$P = \frac{N}{D'}$
The Diametral Pitch	The Outside Diameter and Number of Teeth	Divide Number of Teeth plus 2 by Outside Diameter	$P = \frac{N+2}{D}$
Pitch Diameter	The Number of Teeth and Diametral Pitch	Divide Number of Teeth by the D.P.	$D' = \frac{N}{P}$
Pitch Diameter	The Number of Teeth and Outside Diameter	Divide the product of outside Diameter and Number of Teeth by Number of Teeth plus 2	$D' = \frac{DN}{N+2}$
Pitch Diameter	The Outside Diameter and Diametral Pitch	Subtract from the Outside Diameter the quotient of 2 divided by the D.P.	$D' = D - \frac{2}{P}$
Pitch Diameter	Addendum and Number of Teeth	Multiply Addendum by the Number of Teeth	$D' = sN$
Outside Diameter	The Number of Teeth and Diametral Pitch	Divide Number of Teeth plus 2 by the D.P.	$D = \frac{N+2}{P}$
Outside Diameter	The Pitch Diameter and Diametral Pitch	Add to the Pitch Diameter the quotient of 2 divided by the D.P.	$D = D' + \frac{2}{P}$

Outside Diameter	The Pitch Diameter and Number of Teeth	Divide the Number of Teeth plus 2 by the quotient of the Number of Teeth divided by the Pitch Diameter	$D = \frac{N + 2}{\frac{N'}{D'}}$
Outside Diameter	The Number of Teeth and Addendum	Multiply the Number of Teeth plus 2 by Addendum	$D = (N + 2)s$
Number of Teeth	The Pitch Diameter and Diametral Pitch	Multiply Pitch Diameter by the D.P.	$N = D'P$
Number of Teeth	The Outside Diameter and Diametral Pitch	Multiply Outside Diameter by the D.P. and subtract 2	$N = DP - 2$
Thickness of Tooth	The Diametral Pitch	Divide 1·5708 by the D.P	$t = \frac{1{\cdot}5708}{P}$
Addendum	The Diametral Pitch	Divide 1 by the D.P. or $s = \frac{D'}{N}$	$s = \frac{1}{P}$
Dedendum	The Diametral Pitch	Divide 1·157 by the D.P.	$s + f = \frac{1{\cdot}157}{P}$
Working Depth	The Diametral Pitch	Divide 2 by the D.P.	$D'' = \frac{2}{P}$
Whole Depth	The Diametral Pitch	Divide 2·157 by the D.P.	$D'' + f = \frac{2{\cdot}157}{P}$
Clearance	The Diametral Pitch	Divide 0·157 by the D.P.	$f = \frac{0{\cdot}157}{P}$
Clearance	Thickness of Tooth	Divide Thickness of Tooth at Pitch Line by 10	$f = \frac{t}{10}$

Wire Gauges—1

Number of Gauge.	Imperial Standard Wire Gauge (S.W.G.)		American or Brown & Sharpe.		Stubs' Warrington Gauge		Gold and Silver (Birmingham).		Lancashire Steel Pinion Wire.	
		mm.					in.	mm.	in.	mm.
	50	12·70					—	—	—	—
	46	11·78					—	—	—	—
5/0	43	10·					—	—	—	—
4/0	40	10·		11·68	·454	11	—	—	—	—
3/0				10·388	·425	10·	—	—	—	—
		·83		·24	·380		—	—	—	—
		·23	32	·23	·340		—	—	—	—
	00	·62	·289	·338	·300		·004	0·101	·227	5·757
	76	·06	·257	·527	·284		·005	0·127	·219	5·558
	52	·40	·229	·808	·259		·008	0·203	·212	5·380
	32	·89	·204	·18	·238		·010	0·254	·207	5·257
	12	·38	·181	·59	·220		·013	0·330	·204	5·181
	92	·88	·162	·11	·203	156	·013	0·330	·201	5·105
7	176	·46	·144	·66	·180	57	·015	0·381	·199	5·048
8	160	·06	·128	·24	·165	187	·016	0·406	·197	4·997
9	144	·66	·114		·148	753	·019	0·482	·194	4·921
10	128	·24	·101		·134	·40	·024	0·61	·191	4·845
11	116	·94	·090		·120		·029	0·736	·188	4·777

12	·104	2·642	·080	2·03	·109	2·768	·034		·185	·697
13	·092	2·336	·071	1·79	·095	2·413	·036	·914	·182	·620
14	·080	2·03	·064	1·625	·083	2·108	·041	·041	·180	·57
15	·072	1·828	·057	1·447	·072	1·828	·047	·143	·178	·513
16	·064	1·625	·050	1·27	·065	1·65	·051	·295	·175	·437
17	·056	1·422	·045	1·14	·058	1·473	·057	·447	·172	·360
18	·048	1·219	·040	1·016	·049	1·244	·061	·549	·168	·263
19	·040	1·016	·035	0·889	·042	1·066	·064	·625	·164	·161
20	·036	0·914	·031	0·787	·035	0·889	·067	·701	·161	·085
21	·032	0·812	·028	0·711	·032	0·812	·072	·828	·157	·988
22	·028	0·711	·025	0·635	·028	0·711	·074	·879	·155	·937
23	·024	0·61	·022	0·558	·025	0·635	·077	·955	·153	·886
24	·022	0·558	·020	0·508	·022	0·558	·082	·082	·151	·835
25	·020	0·508	·017	0·431	·020	0·508	·095	·413	·148	·753
26	·018	0·457	·015	0·381	·018	0·457	·103	·616	·146	·702
27	·016	0·406	·0148	0·376	·016	0·406	·113	·87	·143	·626
28	·0148	0·376	·012	0·304	·0148	0·376	·120	·04	·139	·528
29	·0136	0·345	·0116	0·29	·0136	0·345	·120	·04	·134	·401
30	·012	0·304	·010	0·254	·012	0·304	·126	·193	·127	·217
31	·0116	0·29	·008	0·203	·010	0·254	·133	3·376	·120	·04
32	·0108	0·274	·0079	0·199	·009	0·228	·143	3·626	·115	·917
33	·010	0·254	·007	0·177	·008	0·203	·145	3·677	·112	·840
34	·009	0·228	·006	0·152	·0076	0·192	·148	3·753	·110	·79
35	·008	0·203	·0056	0·142	·005	0·127	·158	4·013	·108	·743
36	·0076	0·193	·005	0·127	·004	0·101	·167	·237	·106	·692

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Wire Gauges—2

Number of Gauge.	*Lancashire Steel Wire Letter Gauge.*		*London or Old English.*		*Morse Steel Wire Gauge for Drills.*		*Music Wire Gauge, English.*		*Music Wire Gauge, Washburn & Moen.*	
	in.	*mm.*	*in.*	*mm.*	*in.*	*mm.*	*in.*	*mm.*	*in.*	*mm.*
7/0	—	—	—	—	—	—	—	—	·008	0·203
6/0	—	—	—	—	—	—	—	—	·009	0·228
5/0	—	—	—	—	—	—	—	—	·010	0·254
4/0	—	—	·454	11·53	—	—	—	—	·011	0·279
3/0	—	—	·425	10·787	—	—	—	—	·012	0·304
2/0	—	—	·380	9·65	—	—	—	—	·013	0·330
1/0	—	—	·340	8·63	—	—	—	—	·014	0·355
1	Z ·413	10·48	·300	7·62	·228	5·783	·011	0·279	·015	0·381
2	Y ·404	10·26	·284	7·21	·221	5·60	·012	0·304	·016	0·406
3	X ·397	10·07	·259	6·578	·213	5·406	·013	0·330	·017	0·431
4	W ·386	9·80	·238	6·04	·209	5·308	·014	0·355	·018	0·457
5	V ·377	9·56	·220	5·58	·205	5·207	·015	0·381	·020	0·508
6	U ·368	9·34	·203	5·156	·204	5·181	·016	0·406	·021	0·533
7	T ·358	9·09	·180	4·57	·201	5·105	·017	0·431	·023	0·584
8	S ·348	8·83	·165	4·187	·199	5·048	·019	0·482	·024	0·609
9	R ·339	8·60	·148	3·753	·196	4·972	·020	0·508	·025	0·635
10	Q ·332	8·43	·134	3·40	·193	4·921	·022	0·558	·027	0·685
11	P ·323	8·17	·120	3·04	·191	4·845	·024	0·609	·028	0·711
12	O ·316	8·02	·109	2·768	·189	4·798	·025	0·635	·029	0·736

13	N ·302	7·67	·095	2·413	·185	4·697	·027	0·685	·031	0·787
14	M ·295	7·48	·083	2·108	·182	4·620	·028	0·711	·032	0·812
15	L ·290	7·36	·072	1·828	·180	4·57	·031	0·787	·034	0·863
16	K ·281	7·13	·065	1·65	·177	4·487	·0314	0·797	·036	0·914
17	J ·277	7·02	·058	1·473	·173	4·335	·034	0·863	·037	0·939
18	I ·272	6·90	·049	1·244	·169	4·288	·035	0·889	·039	0·990
19	H ·266	6·75	·040	1·016	·166	4·212	·039	0·990	·041	1·011
20	G ·261	6·62	·035	0·889	·161	4·085	·041	1·041	·043	1·092
21	F ·257	6·5	·031	0·787	·159	4·038	·046	1·168	·046	1·168
22	E ·250	6·35	·029	0·736	·157	3·987	·049	1·244	·048	1·219
23	D ·246	6·24	·027	0·685	·154	3·911	—	—	·051	1·295
24	C ·242	6·14	·025	0·635	·152	3·860	—	—	·055	1·397
25	B ·238	6·04	·023	0·584	·149	3·778	—	—	·058	1·473
26	A ·234	5·94	·020	0·508	·147	3·727	—	—	·062	1·574
27	—	—	·018	0·457	·144	3·651	—	—	·065	1·651
28	—	—	·016	0·406	·140	3·55	—	—	·072	1·828
29	—	—	·015	0·381	·136	3·452	—	—	·076	1·930
30	—	—	·013	0·330	·128	3·243	—	—	·080	2·03
31	—	—	·012	0·304	·120	3·04	—	—	—	—
32	—	—	·011	0·279	·116	2·942	—	—	—	—
33	—	—	·010	0·254	·113	2·866	—	—	—	—
34	—	—	·0095	0·241	·111	2·815	—	—	—	—
35	—	—	·009	0·228	·110	2·79	—	—	—	—
36	—	—	·0075	0·19	·106	2·692	—	—	—	—

For complete details of all wire gauges, see *Wire and Wire Gauge Vest Pocket Book*, obtainable from the publishers of his volume.

Copper Wire Data

Standard Wire Gauge.	Diameter in Inches.	Resistance in Ohms per Yard.	Resistance in Ohms per Pound.	Pounds per Ohm.	Weight in Pounds per 1,000 Yd.	Yards per Pound.	Turns per Inch.				
							Enamel Covered.	Single Silk Covered.	Double Silk Covered.	Single Cotton Covered.	Double Cotton Covered.
10	·128	·001868	·0120	83·3	148·8	6·67		7·64	7·55	7·35	7·04
11	·116	·002275	·0200	50·0	122·2	8·16		8·41	8·30	8·06	7·69
12	·104	·002831	·0280	35·7	98·22	10·23		9·35	9·22	8·93	8·48
13	·092	·003617	·0550	18·1	76·86	13·00		10·5	10·4	10·0	9·43
14	·080	·004784	·0820	12·2	58·12	17·16		12·1	11·8	11·4	10·6
15	·072	·005904	·1400	7·14	47·08	21·23		13·3	13·1	12·5	11·6
16	·064	·007478	·2021	4·95	37·20	26·86	15·0	14·9	14·6	14·1	13·2
17	·056	·009762	·3423	2·38	28·48	35·00	17·1	16·9	16·5	15·9	14·7
18	·048	·01328	·6351	1·56	20·92	47·66	19·8	20·0	19·4	18·5	17·2
19	·040	·01913	1·315	·757	14·53	68·66	23·7	23·8	23·0	21·7	20·0
20	·036	·02362	2·012	·497	11·77	85·00	26·1	26·3	25·3	23·8	21·7
21	·032	·02990	3·221	·309	9·299	107·6	29·4	29·4	28·2	26·3	23·8
22	·028	·03905	5·498	·181	7·120	140·6	33·3	33·3	31·8	29·4	26·3
23	·024	·05313	10·14	·098	5·231	191·6	38·8	38·5	36·4	33·3	29·4
24	·022	·06324	14·38	·069	4·395	228·3	42·1	42·1	40·0	35·7	31·3
25	·020	·07653	21·08	·0471	3·632	275·3	46·0	46·0	43·5	38·5	33·3
26	·018	·09448	32·21	·0309	2·942	340·0	50·6	50·6	47·6	41·7	35·7
27	·0164	·11138	46·55	·0215	2·442	410·0	55·9	55·1	51·6	44·6	37·9

28	·0148	·1398	70·12	·0141	1·989	503·0	61·4	60·4	56·2	48·1	40·2
29	·0136	·1655	98·65	·0101	1·680	596·6	66·2	65·2	60·2	51·0	42·4
30	·0124	·1991	142·75	·0069	1·396	716·6	73·3	72·0	67·1	54·4	44·7
31	·0116	·2275	185·80	·0054	1·222	820·0	77·8	76·3	70·9	56·8	46·3
32	·0108	·2625	248·20	·0040	1·059	943·3	83·0	81·3	75·2	63·3	50·5
33	·0100	·3061	337·50	·0029	·9081	1100	88·9	87·0	80·0	66·7	52·6
34	·0092	·3617	471·00	·0023	·7686	1300	98·0	93·4	85·5	70·4	54·9
35	·0084	·4338	676·50	·0014	·6408	1556	106	101	91·8	80·6	61·0
36	·0076	·5300	1009	·00098	·5254	1903	116	110	102	86·2	64·1
37	·0068	·6620	1574	·00064	·4199	2380	128	120	110	92·6	67·6
38	·0060	·8503	2598	·000385	·3269	3056	143	133	121	100	71·4
39	·0052	1·132	4645	·000217	·2456	4066	168	149	134	109	75·8
40	·0048	1·328	6360	·000156	·2092	4766	180	159	142	114	78·1
41	·0044	1·581	9020	·000112	·1758	5700	194	169	150		
42	·0040	1·913	13150	·000076	·1453	6866	211	191	167		
43	·0036	2·362	20120	·000050	·1177	7500	230	206	179		
44	·0032	2·989	32210	·000030	·0929	10766	253	225	192		
45	·0028	3·904	54980	·000015	·0712	14066	282	247	208		

ABBREVIATIONS

S.W.G.—Standard wire gauge; B.W.G.—Birmingham wire gauge; D.C.C.—double-cotton covered; S.C.C.—single-cotton covered; D.S.C.—double-silk covered; S.S.C.—single-silk covered.

For complete details of all wire gauges, see *Wire and Wire Gauge Vest Pocket Book*, obtainable from the publishers of this volume.

Drilling, Tapping, and Clearing Sizes

Whitworth Threads

Diameter	$\frac{1}{8}$ in.	$\frac{5}{32}$ in.	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.
Tapping size	$\frac{3}{32}$ in.	No. 31	$\frac{9}{64}$ in.	$\frac{3}{16}$ in.	Letter D
Clearing size	$\frac{9}{64}$ in.	$\frac{11}{64}$ in.	$\frac{13}{64}$ in.	$\frac{17}{64}$ in.	$\frac{21}{64}$ in.

B.S.F. Threads

Diameter	$\frac{1}{4}$ in.	$\frac{9}{32}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.
Tapping size	No. 5	Letter B	Letter G	Letter O
Clearing size	$\frac{17}{64}$ in.	$\frac{19}{64}$ in.	$\frac{21}{64}$ in.	$\frac{25}{64}$ in.

B.A. Threads

Diameter	0	1	2	3	4	5	6	7	8
Tapping size	No. 10	No. 17	No. 24	No. 29	No. 32	No. 37	No. 43	No. 46	No. 50
Clearing size	Letter B	No. 3	$\frac{3}{16}$ in.	No. 19	No. 27	No. 30	No. 33	No. 39	No. 43

Wood Screws

Size No.	00	0	1	2	3	4	5	6	7	8
Clearing size	No. 52	No. 51	No. 50	No. 44	No. 40	$\frac{7}{64}$ in.	$\frac{1}{8}$ in.	$\frac{9}{64}$ in.	$\frac{5}{32}$ in.	$\frac{11}{64}$ in.

Twist Drill Gauge Sizes

No. Drill.	*Decimal Size.*	*No. Drill.*	*Decimal Size.*	*No. Drill.*	*Decimal Size.*
1	·2280	21	·1590	41	·0960
2	·2210	22	·1570	42	·0935
3	·2130	23	·1540	43	·0890
4	·2090	24	·1520	44	·0860
5	·2055	25	·1495	45	·0820
6	·2040	26	·1470	46	·0810
7	·2010	27	·1440	47	·0785
8	·1990	28	·1405	48	·0760
9	·1960	29	·1360	49	·0730
10	·1935	30	·1285	50	·0700
11	·1910	31	·1200	51	·0670
12	·1890	32	·1160	52	·0635
13	·1850	33	·1130	53	·0595
14	·1820	34	·1110	54	·0550
15	·1800	35	·1100	55	·0520
16	·1770	36	·1065	56	·0465
17	·1730	37	·1040	57	·0430
18	·1695	38	·1015	58	·0420
19	·1660	39	·0995	59	·0410
20	·1610	40	·0980	60	·0400

Letter Sizes of Drills

A	·234	G	·261	L	·290	Q	·332	V	·377
B	·238	H	·266	M	·295	R	·339	W	·386
C	·242	I	·272	N	·302	S	·348	X	·397
D	·246	J	·277	O	·316	T	·358	Y	·404
E	·250	K	·281	P	·323	U	·368	Z	·413
F	·257								

See also companion work, *Wire and Wire Gauge Vest Pocket Book.*

Tables of Newall Limits

Tolerances in Standard Holes

Class.	*Nominal Diameters.*	*Up to $\frac{1}{2}$ in.*	*$\frac{9}{16}$–1 in.*	*$1\frac{1}{16}$–2 in.*	*$2\frac{1}{16}$–3 in.*	*$3\frac{1}{16}$–4 in.*	*$4\frac{1}{16}$–5 in.*
A	High Limit	+ 0·0002	+ 0·0005	+ 0·0007	+ 0·0010	+ 0·0010	+ 0·0010
	Low Limit	− 0·0002	− 0·0002	− 0·0002	− 0·0005	− 0·0005	− 0·0005
	Tolerance	0·0004	0·0007	0·0009	0·0015	0·0015	0·0015
B	High Limit	+ 0·0005	+ 0·0007	+ 0·0010	+ 0·0012	+ 0·0015	+ 0·0017
	Low Limit	− 0·0005	− 0·0005	− 0·0005	− 0·0007	− 0·0007	− 0·0007
	Tolerance	0·0010	0·0012	0·0015	0·0019	0·0022	0·0024

Allowances for Forced Fits

F	High Limit	+ 0·0010	+ 0·0020	+ 0·0040	+ 0·0060	+ 0·0080	+ 0·0100
	Low Limit	+ 0·0005	+ 0·0015	+ 0·0030	+ 0·0045	+ 0·0060	+ 0·0080
	Tolerance	0·0005	0·0005	0·0010	0·0015	0·0020	0·0020

Allowances for Driving Fits

D	High Limit	+ 0·0005	+ 0·0010	+ 0·0015	+ 0·0025	+ 0·0030	+ 0·0035
	Low Limit	+ 0·0002	+ 0·0007	+ 0·0010	+ 0·0015	+ 0·0020	+ 0·0025
	Tolerance	0·0003	0·0003	0·0005	0·0010	0·0010	0·0010

Tables of Newall Limits—*continued*

ALLOWANCES FOR PUSH FITS

Class.	*Nominal Diameters.*	*Up to ½ in.*	$\frac{9}{16}$–1 *in.*	$1\frac{1}{16}$–2 *in.*	$2\frac{1}{16}$–3 *in.*	$3\frac{1}{16}$–4 *in.*	$4\frac{1}{16}$–5 *in.*
P	High Limit	−0·0002	−0·0002	−0·0002	−0·0005	−0·0005	−0·0005
	Low Limit	−0·0007	−0·0007	−0·0007	−0·0010	−0·0010	−0·0010
	Tolerance	0·0005	0·0005	0·0005	0·0005	0·0005	0·0005

ALLOWANCES FOR RUNNING FITS

Class.	*Nominal Diameters.*	*Up to ½ in.*	$\frac{9}{16}$–1 *in.*	$1\frac{1}{16}$–2 *in.*	$2\frac{1}{16}$–3 *in.*	$3\frac{1}{16}$–4 *in.*	$4\frac{1}{16}$–5 *in.*
X	High Limit	−0·0010	−0·0012	−0·0017	−0·0020	−0·0025	−0·0030
	Low Limit	−0·0020	−0·0027	−0·0035	−0·0042	−0·0050	−0·0057
	Tolerance	0·0010	0·0015	0·0018	0·0022	0·0025	0·0027
Y	High Limit	−0·0007	−0·0010	−0·0012	−0·0015	−0·0020	−0·0022
	Low Limit	−0·0012	−0·0020	−0·0025	−0·0030	−0·0035	−0·0040
	Tolerance	0·0005	0·0010	0·0013	0·0015	0·0015	0·0018
Z	High Limit	−0·0005	−0·0007	−0·0007	−0·0010	−0·0010	−0·0012
	Low Limit	−0·0007	−0·0012	−0·0015	−0·0020	−0·0022	−0·0025
	Tolerance	0·0002	0·0005	0·0008	0·0010	0·0012	0·0013

British Standard Tolerances and Allowances, Running Fits

(Third-quality Work)

	Shaft.				*Hole.*		
	inimum ameter.	*ce ce*		*Allowance (Minimum ifference betwee and Hole*			*ximum meter.*
In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
$\frac{1}{4}$	0·2484	·0016	0·25	·0016	0·2516	·0016	0·2532
$\frac{1}{2}$	0·4979	·0021	0·50	·0028	0·5028	·0028	0·5056
	0·7474	·0026	0·75	·0035	0·7535	·0035	0·7570
1	0·9970	·0030	1·00	·0040	1·0040	·0040	1·0080
$1\frac{1}{2}$	1·4962	·0038	1·50	·0050	1·5050	·0050	1·5100
2	1·9956	·0044	2·00	·0060	2·0060	·0060	2·0120
3	2·9947	·0053	3·00	·0070	3·0070	·0070	3·0140
4	3·9940	·0060	4·00	·0080	4·0080	·0080	4·0160
5	4·9940	·0060	5·00	·0080	5·0080	·0080	5·0160
6	5·9925	·0075	6·00	·0100	6·0100	·0100	6·0200
7	6·9925	·0075	7·00	·0100	7·0100	·0100	7·0200
8	7·9925	·0075	8·00	·0100	8·0100	·0100	8·0200
9	8·9910	·0090	9·00	·0120	9·0120	·0120	9·0240
10	9·9910	·0090	10·00	·0120	0·0120	·0120	10·0240
11	0·9910	·0090	11·00	·0120	1·0120	·0120	11·0240
12	1·9910	·0090	12·00	·0120	2·0120	·0120	12·0240

(Extra Fine-quality Work)

In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
$\frac{1}{4}$	0·2498	·0002	0·25	·0002	0·2502	·0003	0·2505
$\frac{1}{2}$	0·4997	·0003	0·50	·0003	0·5003	·0004	0·5007
$\frac{3}{4}$	0·7496	·0004	0·75	·0004	0·7504	·0004	0·7508
1	0·9995	·0005	1·00	·0005	1·0005	·0005	1·0010
$1\frac{1}{2}$	1·4994	·0006	1·50	·0006	1·5006	·0006	1·5012
2	1·9993	·0007	2·00	·0008	2·0008	·0007	2·0015
3	2·9993	·0007	3·00	·0008	3·0008	·0007	3·0015

British Standard Tolerances and Allowances, Running Fits

(Second-quality Work)

Nominal Diameter.	*Shaft.* *Minimum Diameter.*	*Shaft.* *Tolerance (Difference).*	*Shaft.* *Maximum Diameter.*	*Allowance (Minimum Difference between Shaft and Hole).*	*Hole.* *Minimum Diameter.*	*Hole.* *Tolerance (Difference).*	*Hole.* *Maximum Diameter.*
In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
¼	0·2492	·0008	0·25	·0008	0·2508	·0008	0·2516
½	0·4985	·0015	0·50	·0014	0·5014	·0014	0·5028
¾	0·7482	·0018	0·75	·0017	0·7517	·0018	0·7535
1	0·9980	·0020	1·00	·0020	1·0020	·0020	1·0040
1½	1·4975	·0025	1·50	·0025	1·5025	·0025	1·5050
2	1·9970	·0030	2·00	·0030	2·0030	·0030	2·0060
3	2·9965	·0035	3·00	·0035	3·0035	·0035	3·0070
4	3·9960	·0040	4·00	·0040	4·0040	·0040	4·0080
5	4·9960	·0040	5·00	·0040	5·0040	·0040	5·0080
6	5·9950	·0050	6·00	·0050	6·0050	·0050	6·0100
7	6·9950	·0050	7·00	·0050	7·0050	·0050	7·0100
8	7·9950	·0050	8·00	·0050	8·0050	·0050	8·0100
9	8·9940	·0060	9·00	·0060	9·0060	·0060	9·0120
10	9·9940	·0060	10·00	·0060	10·0060	·0060	10·0120
11	10·9940	·0060	11·00	·0060	11·0060	·0060	11·0120
12	11·9940	·0060	12·00	·0060	12·0060	·0060	12·0120

Limits and Fits for Engineering are dealt with in B.S. 164, 1924, and Supplement No. 164.

Allowances and Tolerances for Running Fits

(*First-quality Work*)

Nominal Diameter.	Shaft. Minimum Diameter.	Shaft. Tolerance (Difference).	Shaft. Maximum Diameter.	Allowance (Minimum Difference between Shaft and Hole).	Hole. Minimum Diameter.	Hole. Tolerance (Difference).	Hole. Maximum Diameter.
In.	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*	*In.*
¼	0·2495	·0005	0·25	·0005	0·2505	·0003	0·2508
½	0·4993	·0007	0·50	·0007	0·5007	·0007	0·5014
¾	0·7491	·0009	0·75	·0008	0·7508	·0009	0·7517
1	0·9990	·0010	1·00	·0010	1·0010	·0010	1·0020
1½	1·4988	·0012	1·50	·0012	1·5012	·0013	1·5025
2	1·9985	·0015	2·00	·0015	2·0015	·0015	2·0030
3	2·9982	·0018	3·00	·0018	3·0018	·0017	3·0035
4	3·9980	·0020	4·00	·0020	4·0020	·0020	4·0040
5	4·9980	·0020	5·00	·0020	5·0020	·0020	5·0040
6	5·9975	·0025	6·00	·0025	6·0025	·0025	6·0050
7	6·9975	·0025	7·00	·0025	7·0025	·0025	7·0050
8	7·9975	·0025	8·00	·0025	8·0025	·0025	8·0050
9	8·9970	·0030	9·00	·0030	9·0030	·0030	9·0060
10	9·9970	·0030	10·00	·0030	10·0030	·0030	10·0060
11	10·9970	·0030	11·00	·0030	11·0030	·0030	11·0060
12	11·9970	·0030	12·00	·0030	12·0030	·0030	12·0060

Chords of Circles

No. of Spaces.	*Multiply Dia. by*	*No. of Spaces.*	*Multiply Dia. by*	*No. of Spaces.*	*Multiply Dia. by*
3	·8660	36	·0872	69	·0455
4	·7071	37	·0848	70	·0449
5	·5878	38	·0826	71	·0442
6	·5000	39	·0805	72	·0436
7	·4339	40	·0785	73	·0430
8	·3827	41	·0765	74	·0424
9	·3420	42	·0747	75	·0419
10	·3090	43	·0730	76	·0413
11	·2817	44	·0713	77	·0408
12	·2588	45	·0698	78	·0403
13	·2393	46	·0682	79	·0398
14	·2225	47	·0668	80	·0393
15	·2079	48	·0654	81	·0388
16	·1951	49	·0641	82	·0383
17	·1838	50	·0628	83	·0378
18	·1736	51	·0616	84	·0374
19	·1646	52	·0604	85	·0370
20	·1564	53	·0592	86	·0365
21	·1490	54	·0581	87	·0361
22	·1423	55	·0571	88	·0357
23	·1362	56	·0561	89	·0353
24	·1305	57	·0551	90	·0349
25	·1253	58	·0541	91	·0345
26	·1205	59	·0532	92	·0341
27	·1161	60	·0523	93	·0338
28	·1120	61	·0515	94	·0334
29	·1081	62	·0507	95	·0331
30	·1045	63	·0499	96	·0327
31	·1012	64	·0491	97	·0324
32	·0980	65	·0483	98	·0321
33	·0951	66	·0476	99	·0317
34	·0923	67	·0469	100	·0314
35	·0896	68	·0462		

Dimensions of Gib Keys

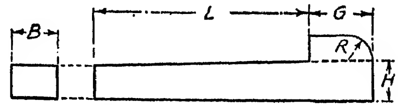


Fig. 375.

Keys of proportions given below are weakest in shear.

The safe twisting moment per inch of length of keys = R × B × S.

R = radius of shaft ;
B = breadth of key ;
S = safe shearing strength of material in key ;
B = $\frac{1}{4}$ × diameter of bore, up to 6 inches ; for larger sizes, B ≑ 0·211 × bore, approximately ;
G = B, approximately ;
H = $\frac{1}{6}$ × diameter of bore up to 6 in. ; for larger sizes, H = $\frac{1}{8}$ × bore ;
h = radius = $\frac{1}{8}$ × diameter of bore, approx., but minimum value = $\frac{3}{16}$ in. ;
L = length of hub + $\frac{1}{2}$ inch.
Taper $\frac{1}{8}$ in. per foot.

Bore and Shaft Diameter.	*Width of key B.*	*Height of key H.*	*Depth of Keyway* $\frac{H}{2}$.	*Radius h.*	*G.*	*Safe Twisting Moment on Key per Inch of Length for S =*		
						5,000	7,500	10,000
$\frac{15}{16}$ to $1\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{16}$	$\frac{3}{32}$	$\frac{3}{16}$	$\frac{1}{4}$	630	940	1,250
$1\frac{3}{16}$ to $1\frac{3}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{8}$	1,170	1,760	2,340
$1\frac{7}{16}$ to $1\frac{5}{8}$	$\frac{3}{8}$	$\frac{1}{4}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{3}{8}$	1,410	2,110	2,810

$1\frac{11}{16}$ to $1\frac{7}{8}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{5}{32}$	$\frac{1}{4}$	$\frac{1}{2}$	2,190	3,280	4,380
$1\frac{15}{16}$ to $2\frac{1}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{1}{2}$	2,500	3,750	5,000
$2\frac{3}{16}$ to $2\frac{3}{8}$	$\frac{5}{8}$	$\frac{3}{8}$	$\frac{3}{16}$	$\frac{3}{8}$	$\frac{5}{8}$	3,520	5,270	7,030
$2\frac{7}{16}$ to $2\frac{5}{8}$	$\frac{5}{8}$	$\frac{7}{16}$	$\frac{7}{32}$	$\frac{3}{8}$	$\frac{5}{8}$	3,910	5,860	7,810
$2\frac{11}{16}$ to $2\frac{7}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{4}$	5,160	7,730	10,313
$2\frac{15}{16}$ to $3\frac{1}{8}$	$\frac{3}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{3}{4}$	5,620	8,420	11,250
$3\frac{3}{16}$ to $3\frac{3}{8}$	$\frac{7}{8}$	$\frac{9}{16}$	$\frac{9}{32}$	$\frac{1}{2}$	$\frac{7}{8}$	7,110	10,660	14,220
$3\frac{7}{16}$ to $3\frac{5}{8}$	$\frac{7}{8}$	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{2}$	$\frac{7}{8}$	7,660	11,480	15,310
$3\frac{11}{16}$ to $3\frac{7}{8}$	1	$\frac{5}{8}$	$\frac{5}{16}$	$\frac{1}{2}$	1	9,380	14,060	18,750
$3\frac{15}{16}$ to $4\frac{1}{8}$	1	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{1}{2}$	1	10,000	15,000	20,000
$4\frac{3}{16}$ to $4\frac{3}{8}$	$1\frac{1}{8}$	$\frac{11}{16}$	$\frac{11}{32}$	$\frac{5}{8}$	1	11,950	17,930	23,910
$4\frac{7}{16}$ to $4\frac{3}{4}$	$1\frac{1}{8}$	$\frac{3}{4}$	$\frac{3}{8}$	$\frac{5}{8}$	1	12,660	18,980	25,310
$4\frac{13}{16}$ to $5\frac{1}{4}$	$1\frac{1}{4}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{5}{8}$	$1\frac{1}{4}$	15,620	23,440	31,250
$5\frac{5}{16}$ to $5\frac{3}{4}$	$1\frac{3}{8}$	$\frac{7}{8}$	$\frac{7}{16}$	$\frac{3}{4}$	$1\frac{1}{4}$	18,910	28,360	37,810
$5\frac{13}{16}$ to $6\frac{1}{4}$	$1\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$	22,500	33,750	45,000
$6\frac{5}{16}$ to $6\frac{3}{4}$	$1\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{1}{2}$	24,380	36,560	48,750
$6\frac{13}{16}$ to $7\frac{1}{4}$	$1\frac{1}{2}$	1	$\frac{1}{2}$	$\frac{7}{8}$	$1\frac{3}{4}$	26,250	39,380	52,500
$7\frac{5}{16}$ to $7\frac{3}{4}$	$1\frac{5}{8}$	1	$\frac{1}{2}$	1	$1\frac{3}{4}$	30,470	45,700	60,940
$7\frac{13}{16}$ to $8\frac{3}{4}$	$1\frac{3}{4}$	$1\frac{1}{8}$	$\frac{9}{16}$	1	2	36,090	54,140	72,190
$8\frac{13}{16}$ to $9\frac{3}{4}$	2	$1\frac{1}{4}$	$\frac{5}{8}$	$1\frac{1}{8}$	2	46,250	69,380	92,500
$9\frac{13}{16}$ to $10\frac{3}{4}$	$2\frac{1}{4}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{4}$	2	57,660	86,480	115,320
$10\frac{13}{16}$ to $11\frac{3}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{4}$	2	70,310	105,470	140,630
$11\frac{13}{16}$ to $12\frac{3}{4}$	$2\frac{1}{2}$	$1\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{4}$	2	76,560	114,840	153,130

Dimensions of Woodruff Standard Keys

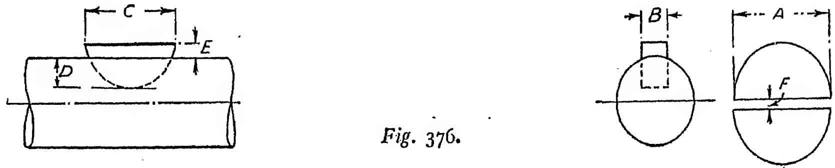
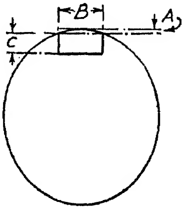


Fig. 376.

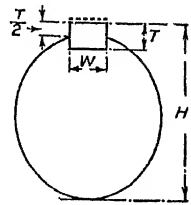
No. of Key and Cutter.	A Diameter of Cutter.	B Thickness of Key and Cutter, in Common and Decimal Fractions.		C Length of Key, Approx.	D Depth to be cut in Shaft, in Common and Decimal Fractions.		E Height of Key above Shaft.	F Centre of Stock to Top of Key.
1	$\frac{1}{2}$	$\frac{1}{16}$	·0625	$\frac{1}{2}$	$\frac{11}{64}$	·1718	$\frac{1}{32}$	$\frac{3}{64}$
2	$\frac{1}{2}$	$\frac{3}{32}$	·0937	$\frac{1}{2}$	$\frac{5}{32}$	·1562	$\frac{3}{64}$	$\frac{3}{64}$
3	$\frac{1}{2}$	$\frac{1}{8}$	·1250	$\frac{1}{2}$	$\frac{9}{64}$	·1406	$\frac{1}{16}$	$\frac{3}{64}$
4	$\frac{5}{8}$	$\frac{3}{32}$	·0937	$\frac{5}{8}$	$\frac{13}{64}$	·2031	$\frac{3}{64}$	$\frac{1}{16}$
5	$\frac{5}{8}$	$\frac{1}{8}$	·1250	$\frac{5}{8}$	$\frac{3}{16}$	·1875	$\frac{1}{16}$	$\frac{1}{16}$
6	$\frac{5}{8}$	$\frac{5}{32}$	·1562	$\frac{5}{8}$	$\frac{11}{64}$	·1718	$\frac{5}{64}$	$\frac{1}{16}$
61	$\frac{5}{8}$	$\frac{3}{16}$	·1875	$\frac{5}{8}$	$\frac{5}{32}$	·1562	$\frac{3}{32}$	$\frac{1}{16}$
7	$\frac{3}{4}$	$\frac{1}{8}$	·1250	$\frac{3}{4}$	$\frac{1}{4}$	·2500	$\frac{1}{16}$	$\frac{1}{16}$
8	$\frac{3}{4}$	$\frac{5}{32}$	·1562	$\frac{3}{4}$	$\frac{15}{64}$	·2343	$\frac{5}{64}$	$\frac{1}{16}$
9	$\frac{3}{4}$	$\frac{3}{16}$	·1875	$\frac{3}{4}$	$\frac{7}{32}$	·2187	$\frac{3}{32}$	$\frac{1}{16}$

91	3/4	1/4	·2500	3/4	3/16	·1875	1/8	1/16
10	7/8	5/32	·1562	7/8	19/64	·2968	5/64	1/16
11	7/8	3/16	·1875	7/8	9/32	·2812	3/32	1/16
12	7/8	7/32	·2187	7/8	17/64	·2656	7/64	1/16
A	7/8	1/4	·2500	7/8	1/4	·2500	1/8	1/16
13	1	3/16	·1875	1	11/32	·3437	3/32	1/16
14	1	7/32	·2187	1	21/64	·3281	7/64	1/16
15	1	1/4	·2500	1	5/16	·3125	1/8	1/16
B	1	5/16	·3125	1	9/32	·2812	5/32	1/16
152	1	3/8	·3750	1	1/4	·2500	3/16	1/16
16	1 1/8	3/16	·1875	1 1/8	25/64	·3906	3/32	5/64
17	1 1/8	7/32	·2187	1 1/8	3/8	·3750	7/64	5/64
18	1 1/8	1/4	·2500	1 1/8	23/64	·3593	1/8	5/64
C	1 1/8	5/16	·3125	1 1/8	21/64	·3281	5/32	5/64
16	1 1/4	3/16	·1875	1 1/4	29/64	·4531	3/32	5/64
20	1 1/4	7/32	·2187	1 1/4	19/32	·5937	7/64	5/64
21	1 1/4	1/4	·2500	1 1/4	27/64	·4218	1/8	5/64
D	1 1/4	5/16	·3125	1 1/4	25/64	·3906	5/32	5/64
E	1 1/4	3/8	·3750	1 1/4	23/64	·3593	3/16	5/64
22	1 3/8	1/4	·2500	1 3/8	15/32	·4687	1/8	3/32
23	1 3/8	5/16	·3125	1 3/8	7/16	·4375	5/32	3/32
F	1 3/8	3/8	·3750	1 3/8	13/32	·4062	3/16	3/32
24	1 1/2	1/4	·2500	1 1/2	33/64	·5156	1/8	7/64
25	1 1/2	5/16	·3125	1 1/2	31/64	·4843	5/32	7/64
G	1 1/2	3/8	·3750	1 1/2	29/64	·4531	3/16	7/64

Depths of Keyseats



Figs. 377 *and* 378



Formula for Height of Arc A.

$$A = R - \sqrt{R^2 - (\tfrac{1}{2}B)^2}$$

The values in the body of the table give the dimension A, which should be added to the depth C of the keyway in order to find a total depth from the outside of the shaft to the bottom of the keyway. When milling keyways, the cutter can be fed down this total depth, and no further measuring is necessary.

Size of Shaft.	*Width of Keyway B.*					*Size of Shaft.*	*Width of Keyway B.*				
	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$		$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$
$\frac{1}{2}$	·032	—	—	—	—	$2\frac{5}{16}$	·006	·010	·015	·020	·027
$\frac{9}{16}$	·028	—	—	—	—	$2\frac{3}{8}$	·006	·010	·015	·020	·026
$\frac{5}{8}$	·025	·041	—	—	—	$2\frac{7}{16}$	·006	·010	·014	·019	·026
$\frac{11}{16}$	·023	·037	—	—	—	$2\frac{1}{2}$	·006	·009	·014	·019	·025
$\frac{3}{4}$	·022	·034	·051	—	—	$2\frac{9}{16}$	·006	·009	·014	·018	·024
$\frac{13}{16}$	·019	·031	·046	—	—	$2\frac{5}{8}$	·006	·009	·013	·018	·024
$\frac{7}{8}$	·017	·028	·042	·058	—	$2\frac{11}{16}$	·005	·008	·013	·018	·023
$\frac{15}{16}$	·016	·026	·039	·054	—	$2\frac{3}{4}$	·005	·008	·013	·017	·023

1	·015	·024	·036	·050	·067	$2\frac{13}{16}$	·005	·008	·012	·017	·022
$1\frac{1}{16}$	·014	·022	·034	·047	·062	$2\frac{7}{8}$	·005	·008	·012	·016	·022
$1\frac{1}{8}$	·013	·021	·032	·044	·058	$2\frac{15}{16}$	·005	·008	·012	·016	·021
$1\frac{3}{16}$	·013	·020	·030	·042	·055	3	·005	·008	·011	·016	·021
$1\frac{1}{4}$	·012	·019	·029	·039	·052	$3\frac{1}{16}$	·005	·008	·011	·015	·020
$1\frac{5}{16}$	·012	·019	·027	·038	·049	$3\frac{1}{8}$	·005	·007	·011	·015	·020
$1\frac{3}{8}$	·012	·018	·026	·036	·047	$3\frac{3}{16}$	·005	·007	·011	·015	·019
$1\frac{7}{16}$	·011	·017	·025	·034	·045	$3\frac{1}{4}$	·004	·007	·011	·014	·019
$1\frac{1}{2}$	·011	·016	·024	·032	·042	$3\frac{5}{16}$	·004	·007	·010	·014	·019
$1\frac{9}{16}$	·010	·015	·023	·030	·041	$3\frac{3}{8}$	·004	·007	·010	·014	·018
$1\frac{5}{8}$	·010	·015	·022	·029	·039	$3\frac{7}{16}$	·004	·007	·010	·014	·018
$1\frac{11}{16}$	·010	·014	·021	·028	·038	$3\frac{1}{2}$	·004	·007	·010	·013	·018
$1\frac{3}{4}$	·009	·014	·020	·027	·037	$3\frac{9}{16}$	·004	·006	·010	·013	·017
$1\frac{13}{16}$	·009	·013	·019	·026	·035	$3\frac{5}{8}$	·004	·006	·010	·013	·017
$1\frac{7}{8}$	·009	·013	·019	·025	·033	$3\frac{11}{16}$	·004	·006	·009	·013	·017
$1\frac{15}{16}$	·009	·012	·018	·025	·032	$3\frac{3}{4}$	·004	·006	·009	·012	·016
2	·008	·012	·017	·024	·031	$3\frac{13}{16}$	·004	·006	·009	·012	·016
$2\frac{1}{16}$	·008	·011	·017	·023	·030	$3\frac{7}{8}$	·004	·006	·009	·012	·016
$2\frac{1}{8}$	·007	·011	·016	·022	·029	$3\frac{15}{16}$	·004	·006	·009	·012	·016
$2\frac{3}{16}$	·007	·010	·016	·022	·029	4	·004	·006	·009	·012	·016
$2\frac{1}{4}$	·007	·010	·015	·021	·028	—	—	—	—	—	—

Instrument-wire Gauges

No. (*S.W.G.*)	*Dia.* (*inches*).	*No.* (*S.W.G.*)	*Dia.* (*inches*).	*No.* (*S.W.G.*)	*Dia.* (*inches*).
4/0	·400	15	·072	33	·0100
3/0	·372	16	·064	34	·0092
2/0	·348	17	·056	35	·0084
0	·324	18	·048	36	·0076
1	·300	19	·040	37	·0068
2	·276	20	·036	38	·0060
3	·252	21	·032	39	·0052
4	·232	22	·028	40	·0048
5	·212	23	·024	41	·0044
6	·192	24	·022	42	·0040
7	·176	25	·020	43	·0036
8	·160	26	·018	44	·0032
9	·144	27	·0164	45	·0028
10	·128	28	·0148	46	·0024
11	·116	29	·0136	47	·0020
12	·104	30	·0124	48	·0016
13	·092	31	·0116	49	·0012
14	·080	32	·0108	50	·0010

Tapers and Angles

Taper per Foot.	Included.			With Centre Line.			Taper per Inch.	Taper per Inch from Centre Line.
	Deg.	Min.	Sec.	Deg.	Min.	Sec.		
$\frac{1}{8}$	0	35	48	0	17	54	·010416	·005208
$\frac{3}{16}$	0	53	44	0	26	52	·015625	·007812
$\frac{1}{4}$	1	11	36	0	35	48	·020833	·010416
$\frac{5}{16}$	1	29	30	0	44	45	·026042	·013021
$\frac{3}{8}$	1	47	24	0	53	42	·031250	·015625
$\frac{7}{16}$	2	5	18	1	2	39	·036458	·018229
$\frac{1}{2}$	2	23	10	1	11	35	·041667	·020833
$\frac{9}{16}$	2	41	4	1	20	32	·046875	·023438
$\frac{5}{8}$	2	59	3	1	29	51	·052084	·026042
$\frac{11}{16}$	3	16	54	1	38	27	·057292	·028646
$\frac{3}{4}$	3	34	48	1	47	24	·062500	·031250
$\frac{13}{16}$	3	52	38	1	56	19	·067708	·033854
$\frac{7}{8}$	4	10	32	2	5	16	·072917	·036456
$\frac{15}{16}$	4	28	24	2	14	12	·078125	·039063
1	4	46	18	2	23	9	·083330	·041667
$1\frac{1}{4}$	5	57	48	2	58	54	·104168	·052084
$1\frac{1}{2}$	7	9	10	3	34	35	·125000	·062500
$1\frac{3}{4}$	8	20	26	4	10	13	·145833	·072917
2	9	31	36	4	45	48	·166666	·083332
$2\frac{1}{2}$	11	53	36	5	56	48	·208333	·104166
3	14	15	0	7	7	30	·250000	·125000
$3\frac{1}{2}$	16	35	40	8	17	50	·291666	·145833
4	18	55	28	9	27	44	·333333	·166666
$4\frac{1}{2}$	21	14	20	10	37	10	·375000	·187500
5	23	32	12	11	46	6	·416666	·208333
6	28	4	20	14	2	10	·500000	·250000

Table of Elements

(Arranged according to Mendeleeff's Periodic Law)

Atomic Number.	*Element.*	*Atomic Weight.*
First Period :		
1	Hydrogen	1·008
2	Helium	4·00
Second Period :		
3	Lithium	6·94
4	Beryllium	9·01
5	Boron	10·82
6	Carbon	12·00
7	Nitrogen	14·01
8	Oxygen	16·00
9	Fluorine	19·00
10	Neon	20·2
Third Period :		
11	Sodium	23·00
12	Magnesium	24·32
13	Aluminium	27·1
14	Silicon	28·3
15	Phosphorus	31·04
16	Sulphur	32·06
17	Chlorine	35·46
18	Argon	39·88
Fourth Period :		
19	Potassium	39·10
20	Calcium	40·07
21	Scandium	45·1
22	Titanium	48·1
23	Vanadium	51·0
24	Chromium	52·0
25	Manganese	54·93
26	Iron	55·84
27	Cobalt	58·97
28	Nickel	58·68
29	Copper	63·57
30	Zinc	65·37
31	Gallium	69·9
32	Germanium	72·5
33	Arsenic	74·96

Table of Elements—*continued*

Atomic Number.	*Element.*	*Atomic Weight.*
34	Selenium	79·2
35	Bromine	79·92
36	Krypton	82·92
Fifth Period :		
37	Rubidium	85·45
38	Strontium	87·63
39	Yttrium	88·7
40	Zirconium	90·6
41	Niobium	93·5
42	Molybdenum . . .	96·0
43		
44	Ruthenium. . . .	101·7
45	Rhodium	102·9
46	Palladium	106·7
47	Silver.	107·88
48	Cadmium	112·40
49	Indium	114·8
50	Tin	118·7
51	Antimony	120·2
52	Tellurium	127·5
53	Iodine	126·92
54	Xenon	130·2
Sixth Period :		
55	Cæsium	132·81
56	Barium	137·37
Rare Earths 57	Lanthanum . . .	139·0
58	Cerium	140·25
59	Praseodymium . . .	140·9
60	Neodymium . . .	144·3
61		
62	Samarium	150·4
63	Europium	152·0
64	Gadolinium . . .	157·3
65	Terbium	159·2
66	Dysprosium . . .	162·5
67	Holmium	163·5
68	Erbium	167·7
69	Thulium	168·5
70	Ytterbium	173·5
71	Lutecium	175·0

Table of Elements—*continued*

Atomic Number.	*Element.*	*Atomic Weight.*
72	Hafnium	178·0
73	Tantalum	181·5
74	Tungsten	184·0
75		
76	Osmium	190·9
77	Iridium	193·1
78	Platinum	195·2
79	Gold	197·2
80	Mercury	200·6
81	Thallium	204·4
82	Lead	207·2
83	Bismuth	209·0
84	Polonium	210·0
85		
86	Niton.	222·0
Seventh Period :		
87		
88	Radium	226·0
89		
90	Thorium	232·12
91	Protoactinium . . .	236·0
92	Uranium	238·2

A Table of Principal Elements arranged in Order of Valency

	Name.	*Symbol.*	*Atomic Weight.*
MONOVALENT	Bromine	Br	79·92
	Chlorine	Cl	35·5
	Fluorine	Fl	19·0
	Hydrogen	H	1·008
	Iodine	I	126·92
	Potassium	K	39·10
	Silver	Ag	107·88
	Sodium	Na	23·0
DIVALENT	Barium	Ba	137·37
	Cadmium	Cd	112·40
	Calcium	Ca	40·07
	Copper	Cu	63·57
	Magnesium	Mg	24·32
	Mercury	Hg	200·6
	Oxygen	O	16·0
	Zinc	Zn	65·37
TRIVALENT	Aluminium	Al	27·1
	Bismuth	Bi	208·0
	Boron	B	10·82
	Cobalt	Co	58·97
	Gold	Au	197·2
	Iron	Fe	55·84
	Nickel	Ni	58·68
TETRAVALENT	Carbon	C	12·005
	Lead	Pb	207·2
	Platinum	Pt	195·2
	Silicon	Si	28·3
	Tin	Sn	118·7
PENTAVALENT	Antimony	Sb	120·2
	Arsenic	As	74·96
	Nitrogen	N	14·01
	Phosphorus	P	31·04
HEXAVALENT	Chromium	Cr	52·0
	Manganese	Mn	54·93
	Sulphur	S	32·06

Wood-screw Proportions

Twist Drills for Wood Screws

No. (or size) of Screw.	*Diameter of Neck or Shank.*	*For Wood or Metal.*			*With Side Lips and Centre for Wood only.*	
			No., etc.	*Diameter.*	*Size.*	*Diameter.*
1	·066	Stubs' Wire Gauge Drills.	51	·067	—	—
2	·080	Stubs' Wire Gauge Drills.	46	·081	—	—
3	·094	Stubs' Wire Gauge Drills.	41	·096	—	—
4	·108	Stubs' Wire Gauge Drills.	35	·110	—	—
5	·122	Stubs' Wire Gauge Drills.	30	·128	$\frac{1}{8}$	·125
6	·136	Stubs' Wire Gauge Drills.	28	·140	—	—
7	·150	Stubs' Wire Gauge Drills.	23	·154	$\frac{5}{32}$	·156
8	·164	Stubs' Wire Gauge Drills.	18	·169	—	—
9	·178	Stubs' Wire Gauge Drills.	14	·182	$\frac{3}{16}$	·187
10	·192	Stubs' Wire Gauge Drills.	9	·196	—	—
11	·206	Stubs' Wire Gauge Drills.	4	·209	$\frac{7}{32}$	·218
12	·220	Stubs' Wire Gauge Drills.	1	·228	—	—
13	·234	Letter Gauge Drills.	B	·238	—	—
14	·248	Letter Gauge Drills.	E	·250	$\frac{1}{4}$	·250
15	·262	Letter Gauge Drills.	H	·266	—	—
16	·276	Letter Gauge Drills.	K	·281	$\frac{9}{32}$	·281
17	·290	Letter Gauge Drills.	M	·295	—	—
18	·304	Letter Gauge Drills.	O	·316	$\frac{5}{16}$	·312
19	·318	Letter Gauge Drills.	P	·323	—	—
20	·332	Letter Gauge Drills.	R	·339	$\frac{11}{32}$	·343
21	·346	Letter Gauge Drills.	S T	·348 ·358	—	—
22	·360	Letter Gauge Drills.	U	·368	$\frac{3}{8}$	·375
23	·374	Letter Gauge Drills.	V	·377	$\frac{3}{8}$	·375
24	·388	Letter Gauge Drills.	X	·397	—	—
25	·402	Letter Gauge Drills.	Z	·413	$\frac{13}{32}$	·406
26	·416		$\frac{27}{64}$	·421	—	—
27	·430		$\frac{7}{16}$	·437	$\frac{7}{16}$	·437
28	·444		$\frac{29}{64}$	·453	—	—
29	·458		$\frac{15}{32}$	·468	$\frac{15}{32}$	·468
30	·472		$\frac{31}{64}$	·484	—	—
31	·486		$\frac{1}{2}$	·500	$\frac{1}{2}$	·500
32	·500		$\frac{33}{64}$	·515	$\frac{1}{2}$	·500

All dimensions in parts of an inch.

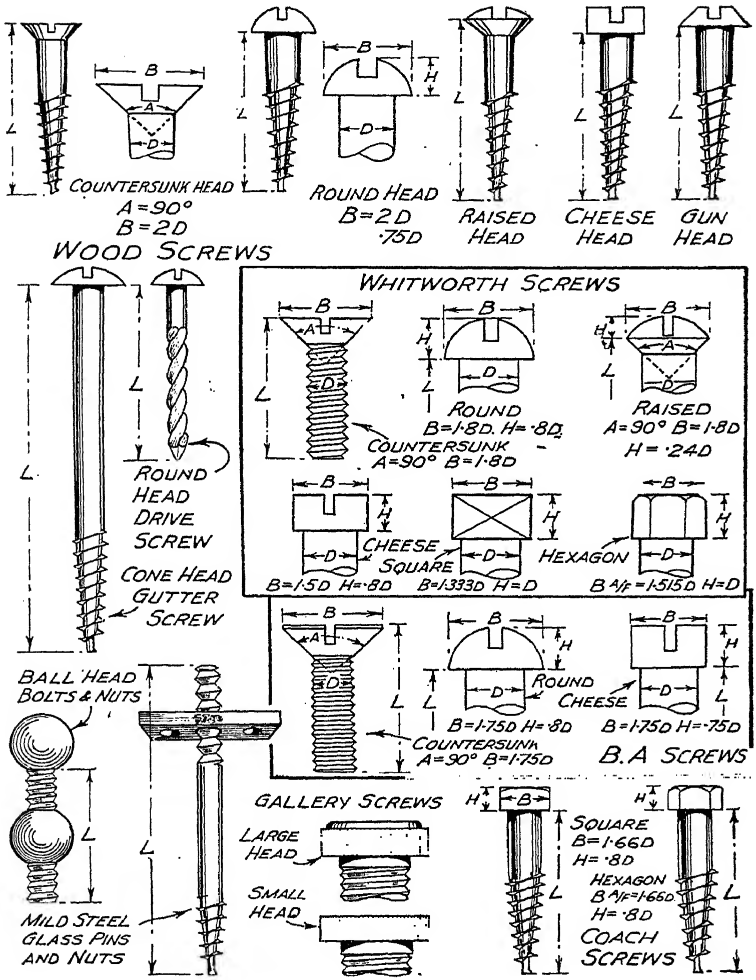


Fig. 379.—Various types of screw threads ond proportions (see table).

Wood-screw Proportions—*continued*

STANDARD WOOD SCREWS

No. of Screw Gauge.	*Diameter. Dec.*	*A In. Approx. Fraction.*	*B In.*	*C In.*	*Slot.*	
					Width.	*Depth.*
0	·05784	1/16	7/64	1/32	1/64	1/64
1	·07100	5/64	9/64	3/64	1/64	1/32
2	·08416	5/64	11/64	3/64	1/64	1/32
3	·09732	3/32	3/16	3/64	1/64	1/32
4	·11048	7/64	7/32	1/16	1/32	1/32
5	·12364	1/8	15/64	1/16	1/32	1/32
6	·13680	9/64	17/64	5/64	1/32	3/64
7	·14996	5/32	19/64	5/64	1/32	3/64
8	·16312	5/32	21/64	3/32	3/64	3/64
9	·17628	11/64	23/64	3/32	3/64	3/64
10	·18944	3/16	3/8	7/64	3/64	1/16
11	·20260	13/64	13/32	7/64	3/64	1/16
12	·21576	7/32	7/16	1/8	3/64	1/16
13	·22892	15/64	29/64	1/8	1/16	1/16
14	·24208	1/4	31/64	9/64	1/16	1/16
15	·25524	1/4	33/64	9/64	1/16	1/16
16	·26840	17/64	17/32	5/32	1/16	5/64
17	·28156	9/32	9/16	5/32	1/16	5/64
18	·29472	19/64	19/32	11/64	5/64	5/64
19	·30788	5/16	39/64	11/64	5/64	5/64
20	·32104	21/64	41/64	11/64	5/64	5/64
21	·33420	21/64	43/64	3/16	5/64	3/32
22	·34736	11/32	11/16	3/16	3/32	3/32
23	·36052	23/64	23/32	13/64	3/32	3/32
24	·37368	3/8	3/4	13/64	3/32	3/32

HORSE-POWER

The unit of work (Horse-power) is based on the assumption that a horse can travel $2\frac{1}{2}$ miles per hour for 8 hours a day, performing the equivalent of pulling a load of 150 lb. out of a shaft by means of a rope. Thus $2\frac{1}{2}$ miles an hour is 220 ft. per minute, and at that speed the load of 150 lb. is raised vertically the same distance. Therefore 300 lb. would be raised 110 ft., or 3,000 lb. raised 11 ft., or 33,000 lb. raised 1 ft. high per minute. The latter is the unit of horse-power, i.e. 33,000 lb. raised 1 ft. high per minute, or 33,000 ft. lb. per minute. Electrical equivalent is 746 watts.

Horse-power of an Electric Motor

$$\text{H.P.} = \frac{\text{Volts} \times \text{Amperes}}{746}$$

Horse-power (Indicated) of a Steam Engine (Single-acting)

$$\text{I H.P.} \qquad 33{,}000$$

where P = Mean effective steam pressure in lb. per sq. in.
L = Length of stroke in feet.
A = Area of piston in sq. in.
N = Number of revolutions per minute.

For a double-acting engine the formula is:

$$\text{I H.P.} = \frac{2\text{PLAN}}{33{,}000}$$

Horse-power of Petrol Engines

R.A.C. Formula: $\text{H.P.} = \frac{D^2N}{16{\cdot}13}$.

Dendy Marshall Formula: $\text{H.P.} = \frac{D^2SNR}{200{,}000}$.

Where S = Stroke in centimetres.
D = Diameter of cylinder in centimetres.
R = Revolutions per minute.
N = Number of cylinders.

A.C.U. Formula: 100 c.c. = 1 H.P.

Logarithms

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	4	8	12	17	21	25	29	33	37
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	4	8	11	15	19	23	26	30	34
12	0792	0828	0864	0899	0934	0969	1004	1038	1072	1106	3	7	10	14	17	21	24	28	31
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	3	6	10	13	16	19	23	26	29
14	1461	1492	1523	1553	1584	1614	1644	1673	1703	1732	3	6	9	12	15	18	21	24	27
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	3	6	8	11	14	17	20	22	25
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	3	5	8	11	13	16	18	21	24
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	2	5	7	10	12	15	17	20	22
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	2	5	7	9	12	14	16	19	21
19	2788	2810	2833	2856	2878	2900	2923	2945	2967	2989	2	4	7	9	11	13	16	18	20
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	2	4	6	8	11	13	15	17	19
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	2	4	6	8	10	12	14	16	18
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	2	4	6	8	10	12	14	15	17
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	2	4	6	7	9	11	13	15	17
24	3802	3820	3858	3856	3874	3892	3909	3927	3945	3962	2	4	5	7	9	11	12	14	16
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	2	3	5	7	9	10	12	14	15
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	2	3	5	7	8	10	11	13	15
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	2	3	5	6	8	9	11	13	14
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	2	3	5	6	8	9	11	12	14
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	1	3	4	6	7	9	10	12	13

30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	1	3	4	6	7	9	10	11	13
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	1	3	4	6	7	8	10	11	12
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	1	3	4	5	7	8	9	11	12
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	1	3	4	5	6	8	9	10	12
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	1	3	4	5	6	8	9	10	11
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	1	2	4	5	6	7	9	10	11
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	1	2	4	5	6	7	8	10	11
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	1	2	3	5	6	7	8	9	10
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	1	2	3	5	6	7	8	9	10
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	1	2	3	4	5	7	8	9	10
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	1	2	3	4	5	6	8	9	10
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	1	2	3	4	5	6	7	8	9
42	6232	6243	6253	6263	6274	6284	6294	6304	6314	6325	1	2	3	4	5	6	7	8	9
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	1	2	3	4	5	6	7	8	9
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	1	2	3	4	5	6	7	8	9
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	1	2	3	4	5	6	7	8	9
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	1	2	3	4	5	6	7	7	8
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	1	2	3	4	5	5	6	7	8
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	1	2	3	4	4	5	6	7	8
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	1	2	3	4	4	5	6	7	8
50	6990	6998	7007	7016	7024	7033	7042	7050	7059	7067	1	2	3	3	4	5	6	7	8
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	1	2	3	3	4	5	6	7	8
52	7160	7168	7177	7185	7193	7202	7210	7218	7226	7235	1	2	2	3	4	5	6	7	7
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	1	2	2	3	4	5	6	6	7
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	1	2	2	3	4	5	6	6	7

Logarithms—*continued*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	1	2	2	3	4	5	5	6	7
56	7482	7490	7497	7505	7513	7520	7528	7536	7543	7551	1	2	2	3	4	5	5	6	7
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	1	2	2	3	4	5	5	6	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	1	1	2	3	4	4	5	6	7
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	1	1	2	3	4	4	5	6	7
60	7782	7789	7796	7803	7810	7818	7825	7832	7839	7846	1	1	2	3	4	4	5	6	6
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	1	1	2	3	4	4	5	6	6
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	1	1	2	3	3	4	5	6	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	1	1	2	3	3	4	5	5	6
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	1	1	2	3	3	4	5	5	6
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	1	1	2	3	3	4	5	5	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	1	1	2	3	3	4	5	5	6
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	1	1	2	3	3	4	5	5	6
68	8325	8331	8338	8344	8351	8357	8363	8370	8376	8382	1	1	2	3	3	4	4	5	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	1	1	2	2	3	4	4	5	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	1	1	2	2	3	4	4	5	6
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	1	1	2	2	3	4	4	5	5
72	8573	8579	8585	8591	8597	8603	8609	8615	8621	8627	1	1	2	2	3	4	4	5	5
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	1	1	2	2	3	4	4	5	5
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	1	1	2	2	3	4	4	5	5

75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	1	1	2	2	3	3	4	5	5
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	1	1	2	2	3	3	4	5	5
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	1	1	2	2	3	3	4	4	5
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	1	1	2	2	3	3	4	4	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	1	1	2	2	3	3	4	4	5
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	1	1	2	2	3	3	4	4	5
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	1	1	2	2	3	3	4	4	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	1	1	2	2	3	3	4	4	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	1	1	2	2	3	3	4	4	5
84	9243	9248	9253	9258	9263	9269	9274	9279	9284	9289	1	1	2	2	3	3	4	4	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	1	1	2	2	3	3	4	4	5
86	9345	9350	9355	9360	9365	9370	9375	9380	9385	9390	1	1	2	2	3	3	4	4	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	0	1	1	2	2	3	3	4	4
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	0	1	1	2	2	3	3	4	4
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	0	1	1	2	2	3	3	4	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	0	1	1	2	2	3	3	4	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	0	1	1	2	2	3	3	4	4
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	0	1	1	2	2	3	3	4	4
93	9685	9689	9694	9699	9703	9708	9713	9717	9722	9727	0	1	1	2	2	3	3	4	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	0	1	1	2	2	3	3	4	4
95	9777	9782	9786	9791	9795	9800	9805	9809	9814	9818	0	1	1	2	2	3	3	4	4
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	0	1	1	2	2	3	3	4	4
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	0	1	1	2	2	3	3	4	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	0	1	1	2	2	3	3	4	4
99	9956	9961	9965	9969	9974	9978	9983	9987	9991	9996	0	1	1	2	2	3	3	3	4

ntiloga

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·00	1000	1002	1005	1007	1009	1012	1014	1016	1019	1021	0	0	1	1	1	1	2	2	2
·01	1023	1026	1028	1030	1033	1035	1038	1040	1042	1045	0	0	1	1	1	1	2	2	2
·02	1047	1050	1052	1054	1057	1059	1062	1064	1067	1069	0	0	1	1	1	1	2	2	2
·03	1072	1074	1076	1079	1081	1084	1086	1089	1091	1094	0	0	1	1	1	1	2	2	2
·04	1096	1099	1102	1104	1107	1109	1112	1114	1117	1119	0	1	1	1	1	2	2	2	2
·05	1122	1125	1127	1130	1132	1135	1138	1140	1143	1146	0	1	1	1	1	2	2	2	2
·06	1148	1151	1153	1156	1159	1161	1164	1167	1169	1172	0	1	1	1	1	2	2	2	2
·07	1175	1178	1180	1183	1186	1189	1191	1194	1197	1199	0	1	1	1	1	2	2	2	2
·08	1202	1205	1208	1211	1213	1216	1219	1222	1225	1227	0	1	1	1	1	2	2	2	3
·09	1230	1233	1236	1239	1242	1245	1247	1250	1253	1256	0	1	1	1	1	2	2	2	3
·10	1259	1262	1265	1268	1271	1274	1276	1279	1282	1285	0	1	1	1	1	2	2	2	3
·11	1288	1291	1294	1297	1300	1303	1306	1309	1312	1315	0	1	1	1	2	2	2	2	3
·12	1318	1321	1324	1327	1330	1334	1337	1340	1343	1346	0	1	1	1	2	2	2	2	3
·13	1349	1352	1355	1358	1361	1365	1368	1371	1374	1377	0	1	1	1	2	2	2	3	3
·14	1380	1384	1387	1390	1393	1396	1400	1403	1406	1409	0	1	1	1	2	2	2	3	3
·15	1413	1416	1419	1422	1426	1429	1432	1435	1439	1442	0	1	1	1	2	2	2	3	3
·16	1445	1449	1452	1455	1459	1462	1466	1469	1472	1476	0	1	1	1	2	2	2	3	3
·17	1479	1483	1486	1489	1493	1496	1500	1503	1507	1510	0	1	1	1	2	2	2	3	3
·18	1514	1517	1521	1524	1528	1531	1535	1538	1542	1545	0	1	1	1	2	2	2	3	3
·19	1549	1552	1556	1560	1563	1567	1570	1574	1578	1581	0	1	1	1	2	2	3	3	3
·20	1585	1589	1592	1596	1600	1603	1607	1611	1614	1618	0	1	1	1	2	2	3	3	3
·21	1622	1626	1629	1633	1637	1641	1644	1648	1652	1656	0	1	1	2	2	2	3	3	3

·22	1660	1663	1667	1671	1675	1679	1683	1687	1690	1694	0	1	1	2	2	2	3	3	3
·23	1698	1702	1706	1710	1714	1718	1722	1726	1730	1734	0	1	1	2	2	2	3	3	4
·24	1738	1742	1746	1750	1754	1758	1762	1766	1770	1774	0	1	1	2	2	2	3	3	4
·25	1778	1782	1786	1791	1795	1799	1803	1807	1811	1816	0	1	1	2	2	2	3	3	4
·26	1820	1824	1828	1832	1837	1841	1845	1849	1854	1858	0	1	1	2	2	3	3	3	4
·27	1862	1866	1871	1875	1879	1884	1888	1892	1897	1901	0	1	1	2	2	3	3	3	4
·28	1905	1910	1914	1919	1923	1928	1932	1936	1941	1945	0	1	1	2	2	3	3	4	4
·29	1950	1954	1959	1963	1968	1972	1977	1982	1986	1991	0	1	1	2	2	3	3	4	4
·30	1995	2000	2004	2009	2014	2018	2023	2028	2032	2037	0	1	1	2	2	3	3	4	4
·31	2042	2046	2051	2056	2061	2065	2070	2075	2080	2084	0	1	1	2	2	3	3	4	4
·32	2089	2094	2099	2104	2109	2113	2118	2123	2128	2133	0	1	1	2	2	3	3	4	4
·33	2138	2143	2148	2153	2158	2163	2168	2173	2178	2183	0	1	1	2	2	3	3	4	4
·34	2188	2193	2198	2203	2208	2213	2218	2223	2228	2234	1	1	2	2	3	3	4	4	5
·35	2239	2244	2249	2254	2259	2265	2270	2275	2280	2286	1	1	2	2	3	3	4	4	5
·36	2291	2296	2301	2307	2312	2317	2323	2328	2333	2339	1	1	2	2	3	3	4	4	5
·37	2344	2350	2355	2360	2366	2371	2377	2382	2388	2393	1	1	2	2	3	3	4	4	5
·38	2399	2404	2410	2415	2421	2427	2432	2438	2443	2449	1	1	2	2	3	3	4	4	5
·39	2455	2460	2466	2472	2477	2483	2489	2495	2500	2506	1	1	2	2	3	3	4	5	5
·40	2512	2518	2523	2529	2535	2541	2547	2553	2559	2564	1	1	2	2	3	4	4	5	5
·41	2570	2576	2582	2588	2594	2600	2606	2612	2618	2624	1	1	2	2	3	4	4	5	5
·42	2630	2636	2642	2649	2655	2661	2667	2673	2679	2685	1	1	2	2	3	4	4	5	6
·43	2692	2698	2704	2710	2716	2723	2729	2735	2742	2748	1	1	2	3	3	4	4	5	6
·44	2754	2761	2767	2773	2780	2786	2793	2799	2805	2812	1	1	2	3	3	4	4	5	6
·45	2818	2825	2831	2838	2844	2851	2858	2864	2871	2877	1	1	2	3	3	4	5	5	6
·46	2884	2891	2897	2904	2911	2917	2924	2931	2938	2944	1	1	2	3	3	4	5	5	6
·47	2951	2958	2965	2972	2979	2985	2992	2999	3006	3013	1	1	3	3	3	4	5	5	6
·48	3020	3027	3034	3041	3048	3055	3062	3069	3076	3083	1	1	2	3	4	4	5	6	6
·49	3090	3097	3105	3112	3119	3126	3133	3141	3148	3155	1	1	2	3	4	4	5	6	6

Antilogarithms—*continued*

	0	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
·50	3162	3170	3177	3184	3192	3199	3206	3214	3221	3228	1	1	2	3	4	4	5	6	7
·51	3236	3243	3251	3258	3266	3273	3281	3289	3296	3304	1	2	2	3	4	5	5	6	7
·52	3311	3319	3327	3334	3342	3350	3357	3365	3373	3381	1	2	2	3	4	5	5	6	7
·53	3388	3396	3404	3412	3420	3428	3436	3443	3451	3459	1	2	2	3	4	5	6	6	7
·54	3467	3475	3483	3491	3499	3508	3516	3524	3532	3540	1	2	2	3	4	5	6	6	7
·55	3548	3556	3565	3573	3581	3589	3597	3606	3614	3622	1	2	2	3	4	5	6	7	7
·56	3631	3639	3648	3656	3664	3673	3681	3690	3698	3707	1	2	3	3	4	5	6	7	8
·57	3715	3724	3733	3741	3750	3758	3767	3776	3784	3793	1	2	3	3	4	5	6	7	8
·58	3802	3811	3819	3828	3837	3846	3855	3864	3873	3882	1	2	3	4	4	5	6	7	8
·59	3890	3899	3908	3917	3926	3936	3945	3954	3963	3972	1	2	3	4	5	5	6	7	8
·60	3981	3990	3999	4009	4018	4027	4036	4046	4055	4064	1	2	3	4	5	6	6	7	8
·61	4074	4083	4093	4102	4111	4121	4130	4140	4150	4159	1	2	3	4	5	6	7	8	9
·62	4169	4178	4188	4198	4207	4217	4227	4236	4246	4256	1	2	3	4	5	6	7	8	9
·63	4266	4276	4285	4295	4305	4315	4325	4335	4345	4355	1	2	3	4	5	6	7	8	9
·64	4365	4375	4385	4395	4406	4416	4426	4436	4446	4457	1	2	3	4	5	6	7	8	9
·65	4467	4477	4487	4498	4508	4519	4529	4539	4550	4560	1	2	3	4	5	6	7	8	9
·66	4571	4581	4592	4603	4613	4624	4634	4645	4656	4667	1	2	3	4	5	6	7	9	10
·67	4677	4688	4699	4710	4721	4732	4742	4753	4764	4775	1	2	3	4	5	7	8	9	10
·68	4786	4797	4808	4819	4831	4842	4853	4864	4875	4887	1	2	3	4	6	7	8	9	10
·69	4898	4909	4920	4932	4943	4955	4966	4977	4989	5000	1	2	3	5	6	7	8	9	10
·70	5012	5023	5035	5047	5058	5070	5082	5093	5105	5117	1	2	4	5	6	7	8	9	11
·71	5129	5140	5152	5164	5176	5188	5200	5212	5224	5236	1	2	4	5	6	7	8	10	11

·72	5248	5260	5272	5284	5297	5309	5321	5333	5346	5358	1	2	4	5	6	7	9	10	11
·73	5370	5383	5395	5408	5420	5433	5445	5458	5470	5483	1	3	4	5	6	8	9	10	11
·74	5495	5508	5521	5534	5546	5559	5572	5585	5598	5610	1	3	4	5	6	8	9	10	12
·75	5623	5636	5649	5662	5675	5689	5702	5715	5728	5741	1	3	4	5	7	8	9	10	12
·76	5754	5768	5781	5794	5808	5821	5834	5848	5861	5875	1	3	4	5	7	8	9	11	12
·77	5888	5902	5916	5929	5943	5957	5970	5984	5998	6012	1	3	4	5	7	8	10	11	12
·78	6026	6039	6053	6067	6081	6095	6109	6124	6138	6152	1	3	4	6	7	8	10	11	13
·79	6166	6180	6194	6209	6223	6237	6252	6266	6281	6295	1	3	4	6	7	9	10	11	13
·80	6310	6324	6339	6353	6368	6383	6397	6412	6427	6442	1	3	4	6	7	9	10	12	13
·81	6457	6471	6486	6501	6516	6531	6546	6561	6577	6592	2	3	5	6	8	9	11	12	14
·82	6607	6622	6637	6653	6668	6683	6699	6714	6730	6745	2	3	5	6	8	9	11	12	14
·83	6761	6776	6792	6808	6823	6839	6855	6871	6887	6902	2	3	5	6	8	9	11	13	14
·84	6918	6934	6950	6966	6982	6998	7015	7031	7047	7063	2	3	5	6	8	10	11	13	15
·85	7079	7096	7112	7129	7145	7161	7178	7194	7211	7228	2	3	5	7	8	10	12	13	15
·86	7244	7261	7278	7295	7311	7328	7345	7362	7379	7396	2	3	5	7	8	10	12	13	15
·87	7413	7430	7447	7464	7482	7499	7516	7534	7551	7568	2	4	5	7	9	10	12	14	16
·88	7586	7603	7621	7638	7656	7674	7691	7709	7727	7745	2	4	5	7	9	11	12	14	16
·89	7762	7780	7798	7816	7834	7852	7870	7889	7907	7925	2	4	5	7	9	11	13	14	16
·90	7943	7962	7980	7998	8017	8035	8054	8072	8091	8110	2	4	6	7	9	11	13	15	17
·91	8128	8147	8166	8185	8204	8222	8241	8260	8279	8299	2	4	6	8	9	11	13	15	17
·92	8318	8337	8356	8375	8395	8414	8433	8453	8472	8492	2	4	6	8	10	12	14	15	17
·93	8511	8531	8551	8570	8590	8610	8630	8650	8670	8690	2	4	6	8	10	12	14	16	18
·94	8710	8730	8750	8770	8790	8810	8831	8851	8872	8892	2	4	6	8	10	12	14	16	18
·95	8913	8933	8954	8974	8995	9016	9036	9057	9078	9099	2	4	6	8	10	12	15	17	19
·96	9120	9141	9162	9183	9204	9226	9247	9268	9290	9311	2	4	6	8	11	13	15	17	19
·97	9333	9354	9376	9397	9419	9441	9462	9484	9506	9528	2	4	7	9	11	13	15	17	20
·98	9550	9572	9594	9616	9638	9661	9683	9705	9727	9750	2	4	7	9	11	13	16	18	20
·99	9772	9795	9817	9840	9863	9886	9908	9931	9954	9977	2	5	7	9	11	14	16	18	20

NATURAL SINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
0	′0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0366	0384	0401	0419	0436	0454	0471	0488	0506	3	6	9	12	15
3	·0523	0541	0558	0576	0593	0610	0628	0645	0663	0680	3	6	9	12	15
4	·0698	0715	0732	0750	0767	0785	0802	0819	0837	0854	3	6	9	12	14
5	·0872	0889	0906	0924	0941	0958	0976	0993	1011	1028	3	6	9	12	14
6	·1045	1063	1080	1097	1115	1132	1149	1167	1184	1201	3	6	9	12	14
7	·1219	1236	1253	1271	1288	1305	1323	1340	1357	1374	3	6	9	12	14
8	·1392	1409	1426	1444	1461	1478	1495	1513	1530	1547	3	6	9	12	14
9	·1564	1582	1599	1616	1633	1650	1668	1685	1702	1719	3	6	9	12	14
10	·1736	1754	1771	1788	1805	1822	1840	1857	1874	1891	3	6	9	11	14
11	·1908	1925	1942	1959	1977	1994	2011	2028	2045	2062	3	6	9	11	14
12	·2079	2096	2113	2130	2147	2164	2181	2198	2215	2233	3	6	9	11	14
13	·2250	2267	2284	2300	2317	2334	2351	2368	2385	2402	3	6	8	11	14
14	·2419	2436	2453	2470	2487	2504	2521	2538	2554	2571	3	6	8	11	14
15	·2588	2605	2622	2639	2656	2672	2689	2706	2723	2740	3	6	8	11	14
16	·2756	2773	2790	2807	2823	2840	2857	2874	2890	2907	3	6	8	11	14
17	·2924	2940	2957	2974	2990	3007	3024	3040	3057	3074	3	6	8	11	14
18	·3090	3107	3123	3140	3156	3173	3190	3206	3223	3239	3	6	8	11	14
19	·3256	3272	3289	3305	3322	3338	3355	3371	3387	3404	3	5	8	11	14
20	·3420	3437	3453	3469	3486	3502	3518	3535	3551	3567	3	5	8	11	14
21	·3584	3600	3616	3633	3649	3665	3681	3697	3714	3730	3	5	8	11	14
22	·3746	3762	3778	3795	3811	3827	3843	3859	3875	3891	3	5	8	11	14
23	·3907	3923	3939	3955	3971	3987	4003	4019	4035	4051	3	5	8	11	14
24	·4067	4083	4099	4115	4131	4147	4163	4179	4195	4210	3	5	8	11	13
25	·4226	4242	4258	4274	4289	4305	4321	4337	4352	4368	3	5	8	11	13
26	·4384	4399	4415	4431	4446	4462	4478	4493	4509	4524	3	5	8	10	13
27	·4540	4555	4571	4586	4602	4617	4633	4648	4664	4679	3	5	8	10	13
28	·4695	4710	4726	4741	4756	4772	4787	4802	4818	4833	3	5	8	10	13
29	·4848	4863	4879	4894	4909	4924	4939	4955	4970	4985	3	5	8	10	13
30	·5000	5015	5030	5045	5060	5075	5090	5105	5120	5135	3	5	8	10	13
31	·5150	5165	5180	5195	5210	5225	5240	5255	5270	5284	2	5	7	10	12
32	·5299	5314	5329	5344	5358	5373	5388	5402	5417	5432	2	5	7	10	12
33	·5446	5461	5476	5490	5505	5519	5534	5548	5563	5577	2	5	7	10	12
34	·5592	5606	5621	5635	5650	5664	5678	5693	5707	5721	2	5	7	10	12
35	·5736	5750	5764	5779	5793	5807	5821	5835	5850	5864	2	5	7	9	12
36	·5878	5892	5906	5920	5934	5948	5962	5976	5990	6004	2	5	7	9	12
37	·6018	6032	6046	6060	6074	6088	6101	6115	6129	6143	2	5	7	9	12
38	·6157	6170	6184	6198	6211	6225	6239	6252	6266	6280	2	5	7	9	11
39	·6293	6307	6320	6334	6347	6361	6374	6388	6401	6414	2	4	7	9	11
40	·6428	6441	6455	6468	6481	6494	6508	6521	6534	6547	2	4	7	9	11
41	·6561	6574	6587	6600	6613	6626	6639	6652	6665	6678	2	4	7	9	11
42	·6691	6704	6717	6730	6743	6756	6769	6782	6794	6807	2	4	6	9	11
43	·6820	6833	6845	6858	6871	6884	6896	6909	6921	6934	2	4	6	8	11
44	·6947	6959	6972	6984	6997	7009	7022	7034	7046	7059	2	4	6	8	10
45	·7071	7083	7096	7108	7120	7133	7145	7157	7169	7181	2	4	6	8	10
46	·7193	7206	7218	7230	7242	7254	7266	7278	0290	7302	2	4	6	8	10
47	·7314	7325	7337	7349	7361	7373	7385	7396	7408	7420	2	4	6	8	10
48	·7431	7443	7455	7466	7478	7490	7501	7513	7524	7536	2	4	6	8	10
49	·7547	7559	7570	7581	7593	7604	7615	7627	7638	7649	2	4	6	8	9
50	·7660	7672	7683	7694	7705	7716	7727	7738	7749	7760	2	4	6	7	9
51	·7771	7782	7793	7804	7815	7826	7837	7848	7859	7869	2	4	5	7	9
52	·7880	7891	7902	7912	7923	7934	7944	7955	7965	7976	2	4	5	7	9
53	·7986	7997	8007	8018	8028	8039	8049	8059	8070	8080	2	3	5	7	9

NATURAL SINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
54	·8090	8100	8111	8121	8131	8141	8151	8161	8171	8181	2	3	5	7	8
55	·8192	8202	8211	8221	8231	8241	8251	8261	8271	8281	2	3	5	7	8
56	·8290	8300	8310	8320	8329	8339	8348	8358	8368	8377	2	3	5	6	8
57	·8387	8396	8406	8415	8425	8434	8443	8453	8462	8471	2	3	5	6	8
58	·8480	8490	8499	8508	8517	8526	8536	8545	8554	8563	2	3	5	6	8
59	·8572	8581	8590	8599	8607	8616	8625	8634	8643	8652	1	3	4	6	7
60	·8660	8669	8678	8686	8695	8704	8712	8721	8729	8738	1	3	4	6	7
61	·8746	8755	8763	8771	8780	8788	8796	8805	8813	8821	1	3	4	6	7
62	·8829	8838	8846	8854	8862	8870	8878	8886	8894	8902	1	3	4	5	7
63	·8910	8918	8926	8934	8942	8949	8957	8965	8973	8980	1	3	4	5	6
64	·8988	8996	9003	9011	9018	9026	9033	9041	9048	9056	1	3	4	5	6
65	·9063	9070	9078	9085	9092	9100	9107	9114	9121	9128	1	2	4	5	6
66	·9135	9143	9150	9157	9164	9171	9178	9184	9191	9198	1	2	3	5	6
67	·9205	9212	9219	9225	9232	9239	9245	9252	9259	9265	1	2	3	4	6
68	·9272	9278	9285	9291	9298	9304	9311	9317	9323	9330	1	2	3	4	5
69	·9336	9342	9348	9354	9361	9367	9373	9379	9385	9391	1	2	3	4	5
70	·9397	9403	9409	9415	9421	9426	9432	9438	9444	9449	1	2	3	4	5
71	·9455	9461	9466	9472	9478	9483	9489	9494	9500	9505	1	2	3	4	5
72	·9511	9516	9521	9527	9532	9537	9542	9548	9553	9558	1	2	3	3	4
73	·9563	9568	9573	9578	9583	9588	9593	9598	9603	9608	1	2	2	3	4
74	·9613	9617	9622	9627	9632	9636	9641	9646	9650	9655	1	2	2	3	4
75	·9659	9664	9668	9673	9677	9681	9686	9690	9694	9699	1	1	2	3	4
76	·9703	9707	9711	9715	9720	9724	9728	9732	9736	9740	1	1	2	3	3
77	·9744	9748	9751	9755	9759	9763	9767	9770	9774	9778	1	1	2	3	3
78	·9781	9785	9789	9792	9796	9799	9803	9806	9810	9813	1	1	2	2	3
79	·9816	9820	9823	9826	9829	9833	9836	9839	9842	9845	1	1	2	2	3
80	·9848	9851	9854	9857	9860	9863	9866	9869	9871	9874	0	1	1	2	2
81	·9877	9880	9882	9885	9888	9890	9893	9895	9898	9900	0	1	1	2	2
82	·9903	9905	9907	9910	9912	9914	9917	9919	9921	9923	0	1	1	2	2
83	·9925	9928	9930	9932	9934	9936	9938	9940	9942	9943	0	1	1	1	2
84	·9945	9947	9949	9951	9952	9954	9956	9957	9959	9960	0	1	1	1	2
85	·9962	9963	9965	9966	9968	9969	9971	9972	9973	9974	0	0	1	1	1
86	·9976	9977	9978	9979	9980	9981	9982	9983	9984	9985	0	0	1	1	1
87	·9986	9987	9988	9989	9990	9990	9991	9992	9993	9993	0	0	0	1	1
88	·9994	9995	9995	9996	9996	9997	9997	9997	9998	9998	0	0	0	0	0
89	·9998	9999	9999	9999	9999	1·000	1·000	1·000	1·000	1·000	0	0	0	0	0

LOGARITHMIC SINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
0	—∞	7·2419	5429	7190	8439	9408	0200	0870	1450	1961					
1	8·2419	2832	3210	3558	3880	4179	4459	4723	4971	5206					
2	8·5428	5640	5842	6035	6220	6397	6567	6731	6889	7041					
3	8·7188	7330	7468	7602	7731	7857	7979	8098	8213	8326					
4	8·8436	8543	8647	8749	8849	8946	9042	9135	9226	9315	16	32	48	64	80
5	8·9403	9489	9573	9655	9736	9816	9894	9970	0046	0120	13	26	39	52	65
6	9·0192	0264	0334	0403	0472	0539	0605	0670	0734	0797	11	22	33	44	55
7	9·0859	0920	0981	1040	1099	1157	1214	1271	1326	1381	10	19	29	38	48
8	9·1436	1489	1542	1594	1646	1697	1747	1797	1847	1895	8	17	25	34	42
9	9·1943	1991	2038	2085	2131	2176	2221	2266	2310	2353	8	15	23	30	38

LOGARITHMIC SINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
10	9·2397	2439	2482	2524	2565	2606	2647	2687	2727	2767	7	14	20	27	34
11	9·2806	2845	2883	2921	2959	2997	3034	3070	3107	3143	6	12	19	25	31
12	9·3179	3214	3250	3284	3319	3353	3387	3421	3455	3488	6	11	17	23	28
13	9·3521	3554	3586	3618	3650	3682	3713	3745	3775	3806	5	11	16	21	26
14	9·3837	3867	3897	3927	3957	3986	4015	4044	4073	4102	5	10	15	20	24
15	9·4130	4158	4186	4214	4242	4269	4226	4323	4350	4377	5	9	14	18	23
16	9·4403	4430	4456	4482	4508	4533	4559	4584	4609	4634	4	9	13	17	21
17	9·4659	4684	4709	4733	4757	4781	4805	4829	4853	4876	4	8	12	16	20
18	9·4900	4923	4946	4969	4992	5015	5037	5060	5082	5104	4	8	11	15	19
19	9·5126	5148	5170	5192	5213	5235	5256	5278	5299	5320	4	7	11	14	18
20	9·5341	5361	5382	5402	5423	5443	5463	5484	5504	5523	3	7	10	14	17
21	9·5543	5563	5583	5602	5621	5641	5660	5679	5698	5717	3	6	10	13	16
22	9·5736	5754	5773	5792	5810	5828	5847	5865	5883	5901	3	6	9	12	15
23	9·5919	5937	5954	5972	5990	6007	6024	6042	6059	6076	3	6	9	12	15
24	9·6093	6110	6127	6144	6161	6177	6194	6210	6227	6243	3	6	8	11	14
25	9·6259	6276	6292	6308	6324	6340	6356	6371	6387	6403	3	5	8	11	13
26	9·6418	6434	6449	6465	6480	6495	6510	6526	6541	6556	3	5	8	10	13
27	9·6570	6585	6600	6615	6629	6644	6659	6673	6687	6702	2	5	7	10	12
28	9·6716	6730	6744	6759	6773	6787	6801	6814	6828	6842	2	5	7	9	12
29	9·6856	6869	6883	6896	6910	6923	6937	6950	6963	6977	2	4	7	9	11
30	9·6990	7003	7016	7029	7042	7055	7068	7080	7093	7106	2	4	6	9	11
31	9·7118	7131	7144	7156	7168	7181	7193	7205	7218	7230	2	4	6	8	10
32	9·7242	7254	7266	7278	7290	7302	7314	7326	7338	7349	2	4	6	8	10
33	9·7361	7373	7384	7396	7407	7419	7430	7442	7453	7464	2	4	6	8	10
34	9·7476	7487	7498	7509	7520	7531	7542	7553	7564	7575	2	4	6	7	9
35	9·7586	7597	7607	7618	7629	7640	7650	7661	7671	7682	2	4	5	7	9
36	9·7692	7703	7713	7723	7734	7744	7754	7764	7774	7785	2	3	5	7	9
37	9·7795	7805	7815	7825	7835	7844	7854	7864	7874	7884	2	3	5	7	8
38	9·7893	7903	7913	7922	7932	7941	7951	7960	7970	7979	2	3	5	6	8
39	9·7989	7998	8007	8017	8026	8035	8044	8053	8063	8072	2	3	5	6	8
40	9·8081	8090	8099	8108	8117	8125	8134	8143	8152	8161	1	3	4	6	7
41	9·8169	8178	8187	8195	8204	8213	8221	8230	8238	8247	1	3	4	6	7
42	9·8255	8264	8272	8280	8289	8297	8305	8313	8322	8330	1	3	4	6	7
43	9·8338	8346	8354	8362	8370	8378	8386	8394	8402	8410	1	3	4	5	7
44	9·8418	8426	8433	8441	8449	8457	8464	8472	8480	8487	1	3	4	5	6
45	9·8495	8502	8510	8517	8525	8532	8540	8547	8555	8562	1	2	4	5	6
46	9·8569	8577	8584	8591	8598	8606	8613	8620	8627	8634	1	2	4	5	6
47	9·8641	8648	8655	8662	8669	8676	8683	8690	8697	8704	1	2	3	5	6
48	9·8711	8718	8724	8731	8738	8745	8751	8758	8765	8771	1	2	3	4	6
49	9·8778	8784	8791	8797	8804	8810	8817	8823	8830	8836	1	2	3	4	5
50	9·8843	8849	8855	8862	8868	8874	8880	8887	8893	8899	1	2	3	4	5
51	9·8905	8911	8917	8923	8929	8935	8941	8947	8953	8959	1	2	3	4	5
52	9·8965	8971	8977	8983	8989	8995	9000	9006	9012	9018	1	2	3	4	5
53	9·9023	9029	9035	9041	9046	9052	9057	9063	9069	9074	1	2	3	4	5
54	9·9080	9085	9091	9096	9101	9107	9112	9118	9123	9128	1	2	3	4	5
55	9·9134	9139	9144	9149	9155	9160	9165	9170	9175	9181	1	2	3	3	4
56	9·9186	9191	9196	9201	9206	9211	9216	9221	9226	9231	1	2	3	3	4
57	9·9236	9241	9246	9251	9255	9260	9265	9270	9275	9279	1	2	2	3	4
58	9·9284	9289	9294	9298	9303	9308	9312	9317	9322	9326	1	2	2	3	4
59	9·9331	9335	9340	9344	9349	9351	9358	9362	9367	9371	1	1	2	3	4
60	9·9375	9380	9384	9388	9393	9397	9401	9406	9410	9414	1	1	2	3	4
61	9·9418	9422	9427	9431	9435	9439	9443	9447	9451	9455	1	1	2	3	3
62	9·9459	9463	9467	9471	9475	9479	9483	9487	9491	9495	1	1	2	3	3
63	9·9499	9503	9507	9510	9514	9518	9522	9525	9529	9533	1	1	2	3	3

LOGARITHMIC SINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
64	9·9537	9540	9544	9548	9551	9555	9558	9562	9566	9569	1	1	2	2	3
65	9·9573	9576	9580	9583	9587	9590	9594	9597	9601	9604	1	1	2	2	3
66	9·9607	9611	9614	9617	9621	9624	9627	9631	9634	9637	1	1	2	2	3
67	9·9640	9643	9647	9650	9653	9656	9659	9662	9666	9669	1	1	2	2	3
68	9·9672	9675	9678	9681	9684	9687	9690	9693	9696	9699	0	1	1	2	2
69	9·9702	9704	9707	9710	9713	9716	9719	9722	9724	9727	0	1	1	2	2
70	9·9730	9733	9735	9738	9741	9743	9746	9749	9751	9754	0	1	1	2	2
71	9·9757	9759	9762	9764	9767	9770	9772	9775	9777	9780	0	1	1	2	2
72	9·9782	9785	9787	9789	9792	9794	9797	9799	9801	9804	0	1	1	2	2
73	9·9806	9808	9811	9813	9815	9817	9820	9822	9824	9826	0	1	1	2	2
74	9·9828	9831	9833	9835	9837	9839	9841	9843	9845	9847	0	1	1	1	2
75	9·9849	9851	9853	9855	9857	9859	9861	9863	9865	9867	0	1	1	1	2
76	9·9869	9871	9873	9875	9876	9878	9880	9882	9884	9885	0	1	1	1	2
77	9·9887	9889	9891	9892	9894	9896	9897	9899	9901	9902	0	1	1	1	1
78	9·9904	9906	9907	9909	9910	9912	9913	9915	9916	9918	0	1	1	1	1
79	9·9919	9921	9922	9924	9925	9927	9928	9929	9931	9932	0	0	1	1	1
80	9·9934	9935	9936	9937	9939	9940	9941	9943	9944	9945	0	0	1	1	1
81	9·9946	9947	9949	9950	9951	9952	9953	9954	9955	9956	0	0	1	1	1
82	9·9958	9959	9960	9961	9962	9963	9964	9965	9966	9967	0	0	1	1	1
83	9·9968	9968	9969	9970	9971	9972	9973	9974	9975	9975	0	0	0	0	1
84	9·9976	9977	9978	9978	9979	9980	9981	9981	9982	9983	0	0	0	0	1
85	9·9983	9984	9985	9985	9986	9987	9987	9988	9988	9989	0	0	0	0	0
86	9·9989	9990	9990	9991	9991	9992	9992	9993	9993	9994	0	0	0	0	0
87	9·9994	9994	9995	9995	9996	9996	9996	9996	9997	9997	0	0	0	0	0
88	9·9997	9998	9998	9998	9998	9999	9999	9999	9999	9999	0	0	0	0	0
89	9·9999	9999	10·00	10·00	10·00	10·00	10·00	10·00	10·00	10·00	0	0	0	0	0

NATURAL COSINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
0	1·000	1·000	1·000	1·000	1·000	1·000	·9999	9999	9999	9999	0	0	0	0	0
1	·9998	9998	9998	9997	9997	9997	9996	9996	9995	9995	0	0	0	0	0
2	·9994	9993	9993	9992	9991	9990	9990	9989	9988	9987	0	0	0	1	1
3	·9986	9985	9984	9983	9982	9981	9980	9979	9978	9977	0	0	1	1	1
4	·9976	9974	9973	9972	9971	9969	9968	9966	9965	9963	0	0	1	1	1
5	·9962	9960	9959	9957	9956	9954	9952	9951	9949	9947	0	1	1	1	2
6	·9945	9943	9942	9940	9938	9936	9934	9932	9930	9928	0	1	1	1	2
7	·9925	9923	9921	9919	9917	9914	9912	9910	9907	9905	0	1	1	2	2
8	·9903	9900	9898	9895	9893	9890	9888	9885	9882	9880	0	1	1	2	2
9	·9877	9874	9871	9869	9866	9863	9860	9857	9854	9851	0	1	1	2	2
10	·9848	9845	9842	9839	9836	9833	9829	9826	9823	9820	1	1	2	2	3
11	·9816	9813	9810	9806	9803	9799	9796	9792	9789	9785	1	1	2	2	3
12	·9781	9778	9774	9770	9767	9763	9759	9755	9751	9748	1	1	2	3	3
13	·9744	9740	9736	9732	9728	9724	9720	9715	9711	9707	1	1	2	3	3
14	·9703	9699	9694	9690	9686	9681	9677	9673	9668	9664	1	1	2	3	4
15	·9659	9655	9650	9646	9641	9636	9632	9627	9622	9617	1	2	2	3	4
16	·9613	9608	9603	9598	9593	9588	9583	9578	9573	9568	1	2	2	3	4
17	·9563	9558	9553	9548	9542	9537	9532	9527	9521	9516	1	2	3	3	4

N.B.—Subtract Mean Differences.

NATURAL COSINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
18	·9511	9505	9500	9494	9489	9483	9478	9472	9466	9461	1	2	3	4	5
19	·9455	9449	9444	9438	9432	9426	9421	9415	9409	9403	1	2	3	4	5
20	·9397	9391	9385	9379	9373	9367	9361	9354	9348	9342	1	2	3	4	5
21	·9336	9330	9323	9317	9311	9304	9298	9291	9285	9278	1	2	3	4	5
22	·9272	9265	9259	9252	9245	9239	9232	9225	9219	9212	1	2	3	4	6
23	·9205	9198	9191	9184	9178	9171	9164	9157	9150	9143	1	2	3	5	6
24	·9135	9128	9121	9114	9107	9100	9092	9085	9078	9070	1	2	4	5	6
25	·9063	9056	9048	9041	9033	9026	9018	9011	9003	8996	1	3	4	5	6
26	·8988	8980	8973	8965	8957	8949	8942	8934	8926	8918	1	3	4	5	6
27	·8910	8902	8894	8886	8878	8870	8862	8854	8846	8838	1	3	4	5	7
28	·8829	8821	8813	8805	8796	8788	8780	8771	8763	8755	1	3	4	6	7
29	·8746	8738	8729	8721	8712	8704	8695	8686	8678	8669	1	3	4	6	7
30	·8660	8652	8643	8634	8625	8616	8607	8599	8590	8581	1	3	4	6	7
31	·8572	8563	8554	8545	8536	8526	8517	8508	8499	8490	2	3	5	6	8
32	·8480	8471	8462	8453	8443	8434	8425	8415	8406	8396	2	3	5	6	8
33	·8387	8377	8368	8358	8348	8339	8329	8320	8310	8300	2	3	5	6	8
34	·8290	8281	8271	8261	8251	8241	8231	8221	8211	8202	2	3	5	7	8
35	·8192	8181	8171	8161	8151	8141	8131	8121	8111	8100	2	3	5	7	8
36	·8090	8080	8070	8059	8049	8039	8028	8018	8007	7997	2	3	5	7	9
37	·7986	7976	7965	7955	7944	7934	7923	7912	7902	7891	2	4	5	7	9
38	·7880	7869	7859	7848	7837	7826	7815	7804	7793	7782	2	4	5	7	9
39	·7771	7760	7749	7738	7728	7716	7705	7694	7683	7672	2	4	6	7	9
40	·7660	7649	7638	7627	7615	7604	7593	7581	7570	7559	2	4	6	8	9
41	·7547	7536	7524	7513	7501	7490	7478	7466	7455	7443	2	4	6	8	10
42	·7431	7420	7408	7396	7385	7373	7361	7349	7337	7325	2	4	6	8	10
43	·7314	7302	7290	7278	7266	7254	7242	7230	7218	7206	2	4	6	8	10
44	·7193	7181	7169	7157	7145	7133	7120	7108	7096	7083	2	4	6	8	10
45	·7071	7059	7046	7034	7022	7009	6997	6984	6972	6959	2	4	6	8	10
46	·6947	6934	6921	6909	6896	6884	6871	6858	6845	6833	2	4	6	8	11
47	·6820	6807	6794	6782	6769	6756	6743	6730	6717	6704	2	4	6	9	11
48	·6691	6678	6665	6652	6639	6626	6613	6600	6587	6574	2	4	7	9	11
49	·6561	6547	6534	6521	6508	6494	6481	6468	6455	6441	2	4	7	9	11
50	·6428	6414	6401	6388	6374	6361	6347	6334	6320	6307	2	4	7	9	11
51	·6293	6280	6266	6252	6239	6225	6211	6198	6184	6170	2	5	7	9	11
52	·6157	6143	6129	6115	6101	6088	6074	6060	6046	6032	2	5	7	9	12
53	·6018	6004	5990	5976	5962	5948	5934	5920	5906	5892	2	5	7	9	12
54	·5878	5864	5850	5835	5821	5807	5793	5779	5764	5750	2	5	7	9	12
55	·5736	5721	5707	5693	5678	5664	5650	5635	5621	5606	2	5	7	10	12
56	·5592	5577	5563	5548	5534	5519	5505	5490	5476	5461	2	5	7	10	12
57	·5446	5432	5417	5402	5388	5373	5358	5344	5329	5314	2	5	7	10	12
58	·5299	5284	5270	5255	5240	5225	5210	5195	5180	5165	2	5	7	10	12
59	·5150	5135	5120	5105	5090	5075	5060	5045	5030	5015	3	5	8	10	13
60	·5000	4985	4970	4955	4939	4924	4909	4894	4879	4863	3	5	8	10	13
61	·4848	4833	4818	4802	4787	4772	4756	4741	4726	4710	3	5	8	10	13
62	·4695	4679	4664	4648	4633	4617	4602	4586	4571	4555	3	5	8	10	13
63	·4540	4524	4509	4493	4478	4462	4446	4431	4415	4399	3	5	8	10	13
64	·4384	4368	4352	4337	4321	4305	4289	4274	4258	4242	3	5	8	11	13
65	·4226	4210	4195	4179	4163	4147	4131	4115	4099	4083	3	5	8	11	13
66	·4067	4051	4035	4019	4003	3987	3971	3955	3939	3923	3	5	8	11	14
67	·3907	3891	3875	3859	3843	3827	3811	3795	3778	3762	3	5	8	11	14
68	·3746	3730	3714	3697	3681	3665	3649	3633	3616	3600	3	5	8	11	14
69	·3584	3567	3551	3535	3518	3502	3486	3469	3453	3437	3	5	8	11	14
70	·3420	3404	3387	3371	3355	3338	3322	3305	3289	3272	3	5	8	11	14

N.B.—Subtract Mean Differences.

NATURAL COSINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
71	·3256	3239	3223	3206	3190	3173	3156	3140	3123	3107	3	6	8	11	14
72	·3090	3074	3057	3040	3024	3007	2990	2974	2957	2940	3	6	8	11	14
73	·2924	2907	2890	2874	2857	2840	2823	2807	2790	2773	3	6	8	11	14
74	·2756	2740	2723	2706	2689	2672	2656	2639	2622	2605	3	6	8	11	14
75	·2588	2571	2554	2538	2521	2504	2487	2470	2453	2436	3	6	8	11	14
76	·2419	2402	2385	2368	2351	2334	2317	2300	2284	2267	3	6	8	11	14
77	·2250	2233	2215	2198	2181	2164	2147	2130	2113	2096	3	6	9	11	14
78	·2079	2062	2045	2028	2011	1994	1977	1959	1942	1925	3	6	9	11	14
79	·1908	1891	1874	1857	1840	1822	1805	1788	1771	1754	3	6	9	11	14
80	·1736	1719	1702	1685	1668	1650	1633	1616	1599	1582	3	6	9	12	14
81	·1564	1547	1530	1513	1495	1478	1461	1444	1426	1409	3	6	9	12	14
82	·1392	1374	1357	1340	1323	1305	1288	1271	1253	1236	3	6	9	12	14
83	·1219	1201	1184	1167	1149	1132	1115	1097	1080	1063	3	6	9	12	14
84	·1045	1028	1011	0993	0976	0958	0941	0924	0906	0889	3	6	9	12	14
85	·0872	0854	0837	0819	0802	0785	0767	0750	0732	0715	3	6	9	12	14
86	·0698	0680	0663	0645	0628	0610	0593	0576	0558	0541	3	6	9	12	15
87	·0523	0506	0488	0471	0454	0436	0419	0401	0384	0366	3	6	9	12	15
88	·0349	0332	0314	0297	0279	0262	0244	0227	0209	0192	3	6	9	12	15
89	·0175	0157	0140	0122	0105	0087	0070	0052	0035	0017	3	6	9	12	15

N.B.—Subtract Mean Differences.

LOGARITHMIC COSINES

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
0	10·0000	0000	0000	0000	0000	0000	0000	0000	0000	9·9999	0	0	0	0	0
1	9·9999	9999	9999	9999	9999	9999	9998	9998	9998	9998	0	0	0	0	0
2	9·9997	9997	9997	9996	9996	9996	9996	9995	9995	9994	0	0	0	0	0
3	9·9994	9994	9993	9993	9992	9992	9991	9991	9990	9990	0	0	0	0	0
4	9·9989	9989	9988	9988	9987	9987	9986	9985	9985	9984	0	0	0	0	0
5	9·9983	9983	9982	9981	9981	9980	9979	9978	9978	9977	0	0	0	0	1
6	9·9976	9975	9975	9974	9973	9972	9971	9970	9969	9968	0	0	0	1	1
7	9·9968	9967	9966	9965	9964	9963	9962	9961	9960	9959	0	0	1	1	1
8	9·9958	9956	9955	9954	9953	9952	9951	9950	9949	9947	0	0	1	1	1
9	9·9946	9945	9944	9943	9941	9940	9939	9937	9936	9935	0	0	1	1	1
10	9·9934	9932	9931	9929	9928	9927	9925	9924	9922	9921	0	0	1	1	1
11	9·9919	9918	9916	9915	9913	9912	9910	9909	9907	9906	0	1	1	1	1
12	9·9904	9902	9901	9899	9897	9896	9894	9892	9891	9889	0	1	1	1	1
13	9·9887	9885	9884	9882	9880	9878	9876	9875	9873	9871	0	1	1	1	2
14	9·9869	9867	9865	9863	9861	9859	9857	9855	9853	9851	0	1	1	1	2
15	9·9849	9847	9845	9843	9841	9839	9837	9835	9833	9831	0	1	1	1	2
16	9·9828	9826	9824	9822	9820	9817	9815	9813	9811	9808	0	1	1	2	2
17	9·9806	9804	9801	9799	9797	9794	9792	9798	9787	9785	0	1	1	2	2
18	9·9782	9780	9777	9775	9772	9770	9767	9764	9762	9759	0	1	1	2	2
19	9·9757	9754	9751	9749	9746	9743	9741	9738	9735	9733	0	1	1	2	2
20	9·9730	9727	9724	9722	9719	9716	9713	9710	9707	9704	0	1	1	2	2
21	9·9702	9699	9696	9693	9690	9687	9684	9681	9678	9675	0	1	1	2	2
22	9·9672	9669	9666	9662	9659	9656	9653	9650	9647	9643	1	1	2	2	3
23	9·9640	9637	9634	9631	9627	9624	9621	9617	9614	9611	1	1	2	2	3
24	9·9607	9604	9601	9597	9594	9590	9587	9583	9580	9576	1	1	2	2	3
25	9·9573	9569	9566	9562	9558	9555	9551	9548	9544	9540	1	1	2	2	3

N.B.—Subtract Mean Differences.

LOGARITHMIC COSINES (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
26	9·9537	9533	9529	9525	9522	9518	9514	9510	9507	9503	1	1	2	3	3
27	9·9499	9495	9491	9487	9483	9479	9475	9471	9467	9463	1	1	2	3	3
28	9·9459	9455	9451	9447	9443	9439	9435	9431	9427	9422	1	1	2	3	3
29	9·9418	9414	9410	9406	9401	9397	9393	9388	9384	9380	1	1	2	3	4
30	9·9375	9371	9367	9362	9358	9353	9349	9344	9340	9335	1	1	2	3	4
31	9·9331	9326	9322	9317	9312	9308	9303	9298	9294	9289	1	2	2	3	4
32	9·9284	9279	9275	9270	9265	9260	9255	9251	9246	9241	1	2	2	3	4
33	9·9236	9231	9226	9221	9216	9211	9206	9201	9196	9191	1	2	3	3	4
34	9·9186	9181	9175	9170	9165	9160	9155	9149	9144	9139	1	2	3	3	4
35	9·9134	9128	9123	9118	9112	9107	9101	9096	9091	9085	1	2	3	4	5
36	9·9080	9074	9069	9063	9057	9052	9046	9041	9035	9029	1	2	3	4	5
37	9·9023	9018	9012	9006	9000	8995	8989	8983	8977	8971	1	2	3	4	5
38	9·8965	8959	8953	8947	8941	8935	8929	8923	8917	8911	1	2	3	4	5
39	9·8905	8899	8893	8887	8880	8874	8868	8862	8855	8849	1	2	3	4	5
40	9·8843	8836	8830	8823	8817	8810	8804	8797	8791	8784	1	2	3	4	5
41	9·8778	8771	8765	8758	8751	8745	8738	8731	8724	8718	1	2	3	5	6
42	9·8711	8704	8697	8690	8683	8676	8669	8662	8655	8648	1	2	3	5	6
43	9·8641	8634	8627	8620	8613	8606	8598	8591	8584	8577	1	2	4	5	6
44	9·8569	8562	8555	8547	8540	8532	8525	8517	8510	8502	1	2	4	5	6
45	9·8495	8487	8480	8472	8464	8457	8449	8441	8433	8426	1	3	4	5	6
46	9·8418	8410	8402	8394	8386	8378	8370	8362	8354	8346	1	3	4	5	7
47	9·8338	8330	8322	8313	8305	8297	8289	8280	8272	8264	1	3	4	6	7
48	9·8255	8247	8238	8230	8221	8213	8204	8195	8187	8178	1	3	4	6	7
49	9·8169	8161	8152	8143	8134	8125	8117	8108	8099	8090	1	3	4	6	7
50	9·8081	8072	8063	8053	8044	8035	8026	8017	8007	7998	2	3	5	6	8
51	9·7989	7979	7970	7960	7951	7941	7932	7922	7913	7903	2	3	5	6	8
52	9·7893	7884	7874	7864	7854	7844	7835	7825	7815	7805	2	3	5	7	8
53	9·7795	7785	7774	7764	7754	7744	7734	7723	7713	7703	2	3	5	7	9
54	9·7692	7682	7671	7661	7650	7640	7629	7618	7607	7597	2	4	5	7	9
55	9·7586	7575	7564	7553	7542	7531	7520	7509	7498	7487	2	4	6	7	9
56	9·7476	7464	7453	7442	7430	7419	7407	7396	7384	7373	2	4	6	8	10
57	9·7361	7349	7338	7326	7314	7302	7290	7278	7266	7254	2	4	6	8	10
58	9·7242	7230	7218	7205	7193	7181	7168	7156	7144	7131	2	4	6	8	10
59	9·7118	7106	7093	7080	7068	7055	7042	7029	7016	7003	2	4	6	9	11
60	9·6990	6977	6963	6950	6937	6923	6910	6896	6883	6869	2	4	7	9	11
61	9·6856	6842	6828	6814	6801	6787	6773	6759	6744	6730	2	5	7	9	12
62	9·6716	6702	6687	6673	6659	6644	6629	6615	6600	6585	2	5	7	10	12
63	9·6570	6556	6541	6526	6510	6495	6480	6465	6449	6434	3	5	8	10	13
64	9·6418	6403	6387	6371	6356	6340	6324	6308	6292	6276	3	5	8	11	13
65	9·6259	6243	6227	6210	6194	6177	6161	6144	6127	6110	3	6	8	11	14
66	9·6093	6076	6059	6042	6024	6007	5990	5972	5954	5937	3	6	9	12	15
67	9·5919	5901	5883	5865	5847	5828	5810	5792	5773	5754	3	6	9	12	15
68	9·5736	5717	5698	5679	5660	5641	5621	5602	5583	5563	3	6	10	13	16
69	9·5543	5523	5504	5484	5463	5443	5423	5402	5382	5361	3	7	10	14	17
70	9·5341	5320	5299	5278	5256	5235	5213	5192	5170	5148	4	7	11	14	18
71	9·5126	5104	5082	5060	5037	5015	4992	4969	4946	4923	4	8	11	15	19
72	9·4900	4876	4853	4829	4805	4781	4757	4733	4709	4684	4	8	12	16	20
73	9·4659	4634	4609	4584	4559	4533	4508	4482	4456	4430	4	9	13	17	21
74	9·4403	4377	4350	4323	4296	4269	4242	4214	4186	4158	5	9	14	18	23
75	9·4130	4102	4073	4044	4015	3986	3957	3927	3897	3867	5	10	15	20	24
76	9·3837	3806	3775	3745	3713	3682	3650	3618	3586	3554	5	11	16	21	26
77	9·3521	3488	3455	3421	3387	3353	3319	3284	3250	3214	6	11	17	23	28
78	9.3179	3143	3107	3070	3034	2997	2959	2921	2883	2845	6	12	19	25	31

N.B.—Subtract Mean Differences.

LOGARITHMIC COSINES (Continued)

grees			12′	18′	24′	30′	36′		48′	54′	Mean Differences 1′	2′	3′	4′	5′
	9·2806	2767	2727	2687	2647	2606	2565	2524	2482	2439	7	14	20	27	34
	9·2397	2353	2310	2266	2221	2176	2131	2085	2038	1991	8	15	23	30	38
	9·1943	1895	1847	1797	1747	1697	1646	1594	1542	1489	8	17	25	34	42
	9·1436	1381	1326	1271	1214	1157	1099	1040	0981	0920	10	19	29	38	48
	9·0859	0797	0734	0670	0605	0539	0472	0403	0334	0264	11	22	33	44	55
	9·0192	0120	0046	$\overline{9970}$	$\overline{9894}$	$\overline{9816}$	$\overline{9736}$	$\overline{9655}$	$\overline{9573}$	$\overline{9489}$	13	26			65
	8·9403	9315	9226	9135	9042	8946	8749	8749	8647	8543	16	32	48	64	80
	8·8436		8213		7979	7857	7731	7602	7468	7330	*Mean* differences no longer sufficiently accurate.				
	8·7188	7041	6889	6731	6567	6397	6220	6035	5842	5640					
	8·5428	5206	4971	4723	4459	4179		3558	3210	2832					
	8·2419	1961	1450	0870	0200	$\overline{9408}$		$\overline{7190}$	$\overline{5429}$	$\overline{2419}$					

N.B.—Subtract Mean Differences.

NATURAL TANGENTS

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
0	·0000	0017	0035	0052	0070	0087	0105	0122	0140	0157	3	6	9	12	15
1	·0175	0192	0209	0227	0244	0262	0279	0297	0314	0332	3	6	9	12	15
2	·0349	0367	0384	0402	0419	0437	0454	0472	0489	0507	3	6	9	12	15
3	·0524	0542	0559	0577	0594	0612	0629	0647	0664	0682	3	6	9	12	15
4	·0699	0717	0734	0752	0769	0787	0805	0822	0840	0857	3	6	9	12	15
5	·0875	0892	0910	0928	0945	0963	0881	0998	1016	1033	3	6	9	12	15
6	·1051	1069	1086	1104	1122	1139	1157	1175	1192	1210	3	6	9	12	15
7	·1228	1246	1263	1281	1299	1317	1334	1352	1370	1388	3	6	9	12	15
8	·1405	1423	1441	1459	1477	1495	1512	1530	1548	1566	3	6	9	12	15
9	·1584	1602	1620	1638	1655	1673	1691	1709	1727	1745	3	6	9	12	15
10	·1763	1781	1799	1817	1835	1853	1871	1890	1908	1926	3	6	9	12	15
11	·1944	1962	1980	1998	2016	2035	2053	2071	2089	2107	3	6	9	12	15
12	·2126	2144	2162	2180	2199	2217	2235	2254	2272	2290	3	6	9	12	15
13	·2309	2327	2345	2364	2382	2401	2419	2438	2456	2475	3	6	9	12	15
14	·2493	2512	2530	2549	2568	2586	2605	2623	2642	2661	3	6	9	12	16
15	·2679	2698	2717	2736	2754	2773	2792	2811	2830	2849	3	6	9	13	16
16	·2867	2886	2905	2924	2943	2962	2981	3000	3019	3038	3	6	9	13	16
17	·3057	3076	3096	3115	3134	3153	3172	3191	3211	3230	3	6	10	13	16
18	·3249	3269	3288	3307	3327	3346	3365	3385	3404	3424	3	6	10	13	16
19	·3443	3463	3482	3502	3522	3541	3561	3581	3600	3620	3	7	10	13	16
20	·3640	3659	3679	3699	3719	3739	3759	3779	3799	3819	3	7	10	13	17
21	·3839	3859	3879	3899	3919	3939	3959	3979	4000	4020	3	7	10	13	17
22	·4040	4061	4081	4101	4122	4142	4163	4183	4204	4224	3	7	10	14	17
23	·4245	4265	4286	4307	4327	4348	4369	4390	4411	4431	3	7	10	14	17
24	·4452	4473	4494	4515	4536	4557	4578	4599	4621	4642	4	7	11	14	18
25	·4663	4684	4706	4727	4748	4770	4791	4813	4834	4856	4	7	11	14	18
26	·4877	4899	4921	4942	4964	4986	5008	5029	5051	5073	4	7	11	15	18
27	·5095	5117	5139	5161	5184	5206	5228	5250	5272	5295	4	7	11	15	18
28	·5317	5340	5362	5384	5407	5430	5452	5475	5498	5520	4	8	11	15	19
29	·5543	5566	5589	5612	5635	5658	5681	5704	5727	5750	4	8	12	15	19
30	·5774	5797	5820	5844	5867	5890	5914	5938	5961	5985	4	8	12	16	20
31	·6009	6032	6056	6080	6104	6128	6152	6176	6200	6224	4	8	12	16	20

NATURAL TANGENTS (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
32	·6249	6273	6297	6322	6346	6371	6395	6420	6445	6469	4	8	12	16	20
33	·6494	6519	6544	6569	6594	6619	6644	6669	6694	6720	4	8	13	17	21
34	·6745	6771	6796	6822	6847	6873	6899	6924	6950	6976	4	9	13	17	21
35	·7002	7028	7054	7080	7107	7133	7159	7186	7212	7239	4	9	13	18	22
36	·7265	7292	7319	7346	7373	7400	7427	7454	7481	7508	5	9	14	18	23
37	·7536	7563	7590	7618	7646	7673	7701	7729	7757	7785	5	9	14	18	23
38	·7813	7841	7869	7898	7926	7954	7983	8012	8040	8069	5	9	14	19	24
39	·8098	8127	8156	8185	8214	8243	8273	8302	8332	8361	5	10	15	20	24
40	·8391	8421	8451	8481	8511	8541	8571	8601	8632	8662	5	10	15	20	25
41	·8693	8724	8754	8785	8816	8847	8878	8910	8941	8972	5	10	16	21	26
42	·9004	9036	9067	9099	9131	9163	9195	9228	9260	9293	5	11	16	21	27
43	·9325	9358	9391	9424	9457	9490	9523	9556	9590	9623	6	11	17	22	28
44	·9657	9691	9725	9759	9793	9827	9861	9896	9930	9965	6	11	17	23	29
45	1·0000	0035	0070	0105	0141	0176	0212	0247	0283	0319	6	12	18	24	30
46	1·0355	0392	0428	0464	0501	0538	0575	0612	0649	0686	6	12	18	25	31
47	1·0724	0761	0799	0837	0875	0913	0951	0990	1028	1067	6	13	19	25	32
48	1·1106	1145	1184	1224	1263	1303	1343	1383	1423	1463	7	13	20	27	33
49	1·1504	1544	1585	1626	1667	1708	1750	1792	1833	1875	7	14	21	28	34
50	1·1918	1960	2002	2045	2088	2131	2174	2218	2261	2305	7	14	22	29	36
51	1·2349	2393	2437	2482	2527	2572	2617	2662	2708	2573	8	15	23	30	38
52	1·2799	2846	2892	2938	2985	3032	3079	3127	3175	3222	8	16	24	31	39
53	1·3270	3319	3367	3416	3465	3514	3564	3613	3663	3713	8	16	25	33	41
54	1·3764	3814	3865	3916	3968	4019	4071	4124	4176	4229	9	17	26	34	43
55	1·4281	4335	4388	4442	4496	4550	4605	4659	4715	4770	9	18	27	36	45
56	1·4826	4882	4938	4994	5051	5108	5166	5224	5282	5340	10	19	29	38	48
57	1·5399	5458	5517	5577	5637	5697	5757	5818	5880	5941	10	20	30	40	50
58	1·6003	6066	6128	6191	6255	6319	6383	6447	6512	6577	11	21	32	43	53
59	1·6643	6709	6775	6842	6909	6977	7045	7113	7182	7251	11	23	34	45	56
60	1·7321	7391	7461	7532	7603	7675	7747	7820	7893	7966	12	24	36	48	60
61	1·8040	8115	8190	8265	8341	8418	8495	8572	8650	8728	13	26	38	51	64
62	1·8807	8887	8967	9047	9128	9210	9292	9375	9458	9542	14	27	41	55	68
63	1·9626	9711	9797	9883	9970	$\overline{0057}$	$\overline{0145}$	$\overline{0233}$	$\overline{0323}$	$\overline{0413}$	15	29	44	58	73
64	2·0503	0594	0686	0778	0872	0965	1060	1155	1251	1348	16	31	47	63	78
65	2·1445	1543	1642	1742	1842	1943	2045	2148	2251	2355	17	34	51	68	85
66	2·2460	2566	2673	2781	2889	2998	3109	3220	3332	3445	18	37	55	73	92
67	2·3559	3673	3789	3906	4023	4142	4262	4383	4504	4627	20	40	60	79	99
68	2·4751	4876	5002	5129	5257	5386	5517	5649	5782	5916	22	43	65	87	108
69	2·6051	6187	6325	6464	6605	6746	6889	7034	7179	7326	24	47	71	95	119
70	2·7475	7625	7776	7929	8083	8239	8397	8556	8716	8878	26	52	78	101	131
71	2·9042	9208	9375	9544	9714	9887	$\overline{0061}$	$\overline{0237}$	$\overline{0415}$	$\overline{0595}$	29	58	87	116	145
72	3·0777	0961	1146	1334	1524	1716	1910	2106	2305	2506	32	64	96	129	161
73	3·2709	2914	3122	3332	3544	3759	3977	4197	4420	4646	36	72	108	144	180
74	3·4874	5105	5339	5576	5816	6059	6305	6554	6806	7062	41	81	122	163	204
75	3·7321	7583	7848	8118	8391	8667	8947	9232	9520	9812	46	93	139	186	232
76	4·0108	0408	0713	1022	1335	1653	1976	2303	2635	2972					
77	4·3315	3662	4015	4374	4737	5107	5483	5864	6252	6646					
78	4·7046	7453	7867	8288	8716	9152	9594	$\overline{0045}$	$\overline{0504}$	$\overline{0970}$					
79	5·1446	1929	2422	2924	3435	3955	4486	5026	5578	6140					
80	5·6713	7297	7894	8502	9124	9758	$\overline{0405}$	$\overline{1066}$	$\overline{1742}$	$\overline{2432}$					
81	6·3138	3859	4596	5350	6122	6912	7720	8548	9395	$\overline{0264}$					
82	7·1154	2066	3002	3962	4947	5958	6996	8062	9158	$\overline{0285}$					
83	8·1443	2636	3863	5126	6427	7769	9152	$\overline{0579}$	$\overline{2052}$	$\overline{3572}$					
84	9·5144	9·677	9·845	10·02	10·20	10·39	10·58	10·78	10·99	11·20					

Mean differences no longer sufficiently a curate.

NATURAL TANGENTS (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′ 2′ 3′ 4′ 5′
85	11·430	11·66	11·91	12·16	12·43	12·71	13·00	13·30	13·62	13·95	
86	14·301	14·67	15·06	15·46	15·89	16·35	16·83	17·34	17·89	18·46	*Mean* differences no longer sufficiently accurate.
87	19·081	19·74	20·45	21·20	22·02	22·90	23·86	24·90	26·03	27·27	
88	28·636	30·14	31·82	33·69	35·80	38·19	40·92	44·07	47·74	52·08	
89	57·290	63·66	71·62	81·85	95·49	114·6	143·2	191·0	286·5	573·0	

LOGARITHMIC TANGENTS

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	1′	2′	3′	4′	5′
0	—∞	7·2419	5429	7190	8439	9409	0200	0870	1450	1962					
1	8·2419	2833	3211	3559	3881	4181	4461	4725	4973	5208					
2	8·5431	5643	5845	6038	6223	6401	6571	6736	6894	7046					
3	8·7194	7337	7475	7609	7739	7865	7988	8107	8223	8336					
4	8·8446	8554	8659	8762	8862	8960	9056	9150	9241	9331	16	32	48	64	81
5	8·9420	9506	9591	9674	9756	9836	9915	9992	$\overline{0068}$	$\overline{0143}$	13	26	40	53	66
6	9·0216	0289	0360	0430	0499	0567	0633	0699	0764	0828	11	22	34	45	56
7	9·0891	0954	1015	1076	1135	1194	1252	1310	1367	1423	10	20	29	39	49
8	9·1478	1533	1587	1640	1693	1745	1797	1848	1898	1948	9	17	26	35	43
9	9·1997	2046	2094	2142	2189	2236	2282	2328	2374	2419	8	16	23	31	39
10	9·2463	2507	2551	2594	2637	2680	2722	2764	2805	2846	7	14	21	28	35
11	9·2887	2927	2967	3006	3046	3085	3123	3162	3200	3237	6	13	19	26	32
12	9·3275	3312	3349	3385	3422	3458	3493	3529	3564	3599	6	12	18	24	30
13	9·3634	3668	3702	3736	3770	3804	3837	3870	3902	3935	6	11	17	22	28
14	9·3968	4000	4032	4064	4095	4127	4158	4189	4220	4250	5	10	16	21	26
15	9·4281	4311	4341	4371	4400	4430	4459	4488	4517	4546	5	10	15	20	25
16	9·4575	4603	4632	4660	4688	4716	4744	4771	4799	4826	5	9	14	19	23
17	9·4853	4880	4907	4934	4961	4987	5014	5040	5066	5092	4	9	13	18	22
18	9·5118	5143	5169	5195	5220	5245	5270	5295	5320	5345	4	8	13	17	21
19	9·5370	5394	5419	5443	5467	5491	5516	5539	5563	5587	4	8	12	16	20
20	9·5611	5634	5658	5681	5704	5727	5750	5773	5796	5819	4	8	12	15	19
21	9·5842	5864	5887	5909	5932	5954	5976	5998	6020	6042	4	7	11	15	19
22	9·6064	6086	6108	6129	6151	6172	6194	6215	6236	6257	4	7	11	14	18
23	9·6279	6300	6321	6341	6362	6383	6404	6424	6445	6465	3	7	10	14	17
24	9·6486	6506	6527	6547	6567	6587	6607	6627	6647	6667	3	7	10	13	17
25	9·6687	6706	6726	6746	6765	6785	6804	6824	6843	6863	3	7	10	13	16
26	9·6882	6901	6920	6939	6958	6977	6996	7015	7034	7053	3	6	9	13	16
27	9·7072	7090	7109	7128	7146	7165	7183	7202	7220	7238	3	6	9	12	15
28	9·7257	7275	7293	7311	7330	7348	7366	7384	7402	7420	3	6	9	12	15
29	9·7438	7455	7473	7491	7509	7526	7544	7562	7579	7597	3	6	9	12	15
30	9·7614	7632	7649	7667	7684	7701	7719	7736	7753	7771	3	6	9	12	14
31	9·7788	7805	7822	7839	7856	7873	7890	7907	7924	7941	3	6	9	11	14
32	9·7958	7975	7992	8008	025	8042	8059	8075	8092	8109	3	6	8	11	14
33	9·8125	8142	8158	8175	8191	8208	8224	8241	8257	8274	3	5	8	11	14
34	9·8290	8306	8323	8339	8355	8371	8388	8404	8420	8436	3	5	8	11	14
35	9·8452	8468	8484	8501	8517	8533	8549	8565	8581	8597	3	5	8	11	13
36	9·8613	8629	8644	8660	8676	8692	8708	8724	8740	8755	3	5	8	11	13
37	9·8771	8787	8803	8818	8834	8850	8865	8881	8897	8912	3	5	8	10	13
38	9·8928	8944	8959	8975	8990	9006	9022	9037	9053	9068	3	5	8	10	13

LOGARITHMIC TANGENTS (Continued)

Degrees	0′	6′	12′	18′	24′	30′	36′	42′	48′	54′	Mean Differences 1′	2′	3′	4′	5′
39	9·9084	9099	9115	9130	9146	9161	9176	9192	9207	9223	3	5	8	10	13
40	9·9238	9254	9269	9284	9300	9315	9330	9346	9361	9376	3	5	8	10	13
41	9·9392	9407	9422	9438	9453	9468	9483	9499	9514	9529	3	5	8	10	13
42	9·9544	9560	9575	9590	9605	9621	9636	9651	9666	9681	3	5	8	10	13
43	9·9697	9712	9727	9742	9757	9773	9788	9803	9818	9833	3	5	8	10	13
44	9·9848	9864	9870	9894	9909	9924	9939	9955	9970	9985	3	5	8	10	13
45	10·0000	0015	0030	0045	0061	0076	0091	0106	0121	0136	3	5	8	10	13
46	10·0152	0167	0182	0197	0212	0228	0243	0258	0273	0288	3	5	8	10	13
47	10·0303	0319	0334	0349	0364	0379	0395	0410	0425	0440	3	5	8	10	13
48	10·0456	0471	0486	0501	0517	0532	0547	0562	0578	0593	3	5	8	10	13
49	10·0608	0624	0639	0654	0670	0685	0700	0716	0731	0746	3	5	8	10	13
50	10·0762	0777	0793	0808	0824	0839	0854	0870	0885	0901	3	5	8	10	13
51	10·0916	0932	0947	0963	0978	0994	1010	1025	1041	1056	3	5	8	10	13
52	10·1072	1088	1103	1119	1135	1150	1166	1182	1197	1213	3	5	8	10	13
53	10·1229	1245	1260	1276	1292	1308	1324	1340	1356	1371	3	5	8	11	13
54	10·1387	1403	1419	1435	1451	1467	1483	1499	1516	1532	3	5	8	11	13
55	10·1548	1564	1580	1596	1612	1629	1645	1661	1677	1694	3	5	8	11	14
56	10·1710	1726	1743	1759	1776	1792	1809	1825	1842	1858	3	5	8	11	14
57	10·1875	1891	1908	1925	1941	1958	1975	1992	2008	2025	3	6	8	11	14
58	10·2042	2059	2076	2093	2110	2127	2144	2161	2178	2195	3	6	9	11	14
59	10·2212	2229	2247	2264	2281	2299	2316	2333	2351	2368	3	6	9	12	14
60	10·2386	2403	2421	2428	2456	2474	2491	2509	2527	2545	3	6	9	12	15
61	10·2562	2580	2598	2616	2634	2652	2670	2689	2707	2725	3	6	9	12	15
62	10·2743	2762	2780	2798	2817	2835	2854	2872	2891	2910	3	6	9	12	15
63	10·2928	2947	2966	2985	3004	3023	3042	3061	3080	3099	3	6	9	13	16
64	10·3118	3137	3157	3176	3196	3215	3235	3254	3274	3294	3	6	10	13	16
65	10·3313	3333	3353	3373	3393	3413	3433	3453	3473	3494	3	7	10	13	17
66	10·3514	3535	3555	3576	3596	3617	3638	3659	3679	3700	3	7	10	14	17
67	10·3721	3743	3764	3785	3806	3828	3849	3871	3892	3914	4	7	11	14	18
68	10·3936	3958	3980	4002	4024	4046	4068	4091	4113	4136	4	7	11	15	19
69	10·4158	4181	4204	4227	4250	4273	4296	4319	4342	4366	4	8	12	15	19
70	10·4389	4413	4437	4461	4484	4509	4533	4557	4581	4606	4	8	12	16	20
71	10·4630	4655	4680	4705	4730	4755	4780	4805	4831	4857	4	8	13	17	21
72	10·4882	4908	4934	4960	4986	5013	5039	5066	5093	5120	4	9	13	18	22
73	10·5147	5174	5201	5229	5256	5284	5312	5430	5368	5397	5	9	14	19	23
74	10·5425	5454	5483	5512	5541	5570	5600	5629	5659	5689	5	10	15	20	25
75	10·5719	5750	5780	5811	5842	5873	5905	5936	5968	6000	5	10	16	21	26
76	10·6032	6065	6097	6130	6163	6196	6230	6264	6298	6332	6	11	17	22	28
77	10·6366	6401	6436	6471	6507	6542	6578	6615	6651	6688	6	12	18	24	30
78	10·6725	6763	6800	6838	6877	6915	6954	6994	7033	7073	6	13	19	26	32
79	10·7113	7154	7195	7236	7278	7320	7363	7406	7449	7493	7	14	21	28	35
80	10·7537	7581	7626	7672	7718	7764	7811	7858	7906	7954	8	16	23	31	39
81	10·8003	8052	8102	8152	8203	8255	8307	8360	8413	8467	9	17	26	35	43
82	10·8522	8577	8633	8690	8748	8806	8865	8924	8985	9046	10	20	29	39	49
83	10·9109	9172	9236	9301	9367	9433	9501	9570	9640	9711	11	22	34	45	56
84	10·9784	9857	9932	$\overline{0008}$	$\overline{0085}$	$\overline{0164}$	$\overline{0244}$	$\overline{0326}$	$\overline{0409}$	$\overline{0494}$	13	26	40	53	66
85	11·0580	0669	0759	0850	0944	1040	1138	1238	1341	1446	16	32	48	64	81
86	11·1554	1664	1777	1893	2012	2135	2261	2391	2525	2663	*Mean* differences no longer sufficiently accurate.				
87	11·2806	2954	3106	3264	3429	3599	3777	3962	4155	4357					
88	11·4569	4792	5027	5275	5539	5819	6119	6441	6789	7167					
89	11·7581	8038	8550	9130	9800	$\overline{0591}$	$\overline{1561}$	$\overline{2810}$	$\overline{4571}$	$\overline{7581}$					

Weights of Woods

The weights of dry woods are as follow:

Substance.	*Weight lb. per cub. ft.*	*Substance.*	*Weight lb. per cub. ft.*
Alder	33	Hickory	50
Almond	43	Holly	38
Ash, American	40	Hornbeam	45
Ash, European	43	Ironwood	75
Ash, Mountain	43	Jarrah	57
Balsa	7/8	Juniper	37
Bamboo	25	Lancewood	57
Beech, Common	46	Larch	38
Beech, Australian	33	Lignum-vitæ	83
Birch, American	42	Lime or Linden	32
Birch, English	45	Logwood	57
Boxwood, Cape	52	Mahogany, East Indian	43
Boxwood, West Indian	49	Mahogany, Cuban	47
Boxwood, Common	76	Mahogany, Australian	69
Cedar, Cuban	28	Mahogany, Spanish	48
Cedar, Virginian	33	Maple, Bird's-eye	36
Cedar, Indian	28	Maple, Hard	42
Cherry, American	36	Maple, Soft	38
Cherry, English	38	Oak, African	59
Chestnut, Sweet	40	Oak, American	45
Chestnut, Horse	35	Oak, Danzig	52
Cocus	69	Oak, English	46
Cogwood	67	Pine, Pitch	44
Cork	16	Pine, Red	34
Cottonwood, American	34	Pine, White	27
Cypress	30	Pine, Yellow	33
Dogwood	49	Plane	35
Ebony	73	Poplar	26
Elder	40	Rosewood	55
Elm, American	44	Satinwood	58
Elm, Common	42	Spruce	30
Fir, Danzig	38	Sycamore	40
Fir, Riga	36	Teak	50
Fir, Silver	30	Walnut	41
Fir, Spruce	30	Whitewood	33
Hackmatack	39	Willow	33
Hazel	39	Yew	52

Table of Decimal Equivalents

$\frac{1}{64}$	·015625	$\frac{25}{64}$	·390625	$\frac{43}{64}$	·671875
$\frac{1}{32}$	·03125	$\frac{13}{32}$	·40625	$\frac{11}{16}$	·6875
$\frac{3}{64}$	·046875	$\frac{27}{64}$	·421875	$\frac{45}{64}$	·703125
$\frac{1}{16}$		$\frac{7}{16}$	·4375	$\frac{23}{32}$	·71875
	·078125	$\frac{29}{64}$	·453125	$\frac{47}{64}$	·734375
	·09375	$\frac{15}{32}$	·46875	$\frac{3}{4}$	·7500
	·109375	$\frac{31}{64}$	·484375	$\frac{49}{64}$	·765625
	·1250	$\frac{1}{2}$	·5000	$\frac{25}{32}$	·78125
	·140625	$\frac{33}{64}$	·515625	$\frac{51}{64}$	·796875
	·15625	$\frac{17}{32}$	·53125	$\frac{13}{16}$	·8125
	·171875	$\frac{35}{64}$	·546875	$\frac{53}{64}$	·828125
	·1875	$\frac{9}{16}$	·5625	$\frac{27}{32}$	·84375
	·203125	$\frac{37}{64}$	·578125	$\frac{55}{64}$	·859375
	·21875	$\frac{19}{32}$	·59375	$\frac{7}{8}$	·8750
	·234375	$\frac{39}{64}$	·609375	$\frac{57}{64}$	·890625
	·2500	$\frac{5}{8}$	·6250	$\frac{29}{32}$	·90625
	·265625	$\frac{41}{64}$	·640625	$\frac{59}{64}$	·921875
	·28125	$\frac{21}{32}$	·65625	$\frac{15}{16}$	·9375
	·296875			$\frac{61}{64}$	·953125
	·3125			$\frac{31}{32}$	·96875
	·328125			$\frac{63}{64}$	·984375
	·34375			1	1·0000
	·359375				
	·375				

INDE

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